ILS GLIDE SLOPE PERFORMANCE PREDICTION. VOLUME B

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16. Abstract

A mathematical model for predicting the performance of ILS glide slope arrays in the presence of certain types of terrain irregularities has been developed. The model is discussed in detail and then applied to a number of typical glide slope siting problems for purposes of illustration. A User's Manual for exercising the model forms Part 2 of this report.

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PREFACE

In order to quickly assess the effect of certain types of terrain irregularities on the performance of ILS Glide Slope antenna systems, a mathematical-electromagnetic scattering computer model has been developed.

This work was performed by members of the Modeling and Analysis Section of the Electromagnetic Technology Division, Transportation Systems Center for the Category 1 and 2 ILS Section of the Terminal Navigation Branch of the Systems Research and Development Service, Federal Aviation Administration (FAA).

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PART I. THEORY

1. INTRODUCTION

A mathematical model has been developed for predicting the performance of image-type glide slope arrays in the presence of certain types of terrain irregularities. The basic theory is developed in the following section and then numerical results are presented, illustrating the performance of different glide slope arrays for several terrain configurations.

2. THEORY

The vertical antenna pattern of an image-type glide slope array is determined by the interference between the direct and ground-reflected radiation. The ground-reflected radiation is of course generated by the charges and currents induced in the ground plane by the incident radiation from the glide slope array. For simplicity, we will assume that the ground is perfectly conducting. For a perfect conductor, the surface current density $\vec{K}$ is given by:

$$\vec{K} = \hat{n} \times \vec{H}, \tag{1}$$

where $\hat{n}$ is the unit normal vector pointing out of the ground and $\vec{H}$ is the total magnetic field:

$$\vec{H} = \vec{H}_i + \vec{H}_s, \tag{2}$$

where $\vec{H}_i$ is the incident and $\vec{H}_s$ is the scattered magnetic field.

In terms of the surface current density $\vec{K}$, the ground-reflected or scattered magnetic field $\vec{H}_s$ at a receiver above the ground is given by the following surface integral:

$$\vec{H}_s(\vec{r}_1) = \frac{1}{4\pi} \int_S \vec{K}(\vec{r}) \times \vec{\nabla} G(\vec{r}_1,\vec{r}) ds \tag{3}$$

The position vectors $\vec{r}_1$ and $\vec{r}$ denote, respectively, the position vector of the receiver and the position vector of a source point on the ground plane S relative to some arbitrarily chosen origin of coordinates. The two-point Green's Function $G(\vec{r}_1,\vec{r})$ is given by:

$$G(\vec{r}_1,\vec{r}) = \frac{e^{ik|\vec{r}_1-\vec{r}|}}{|\vec{r}_1-\vec{r}|}, \tag{4}$$

where $k = 2\pi/\lambda$ and λ is the wavelength of the incident radiation.

We will adopt the physical optics model for the surface current density $\vec{K}$. Specifically, we will assume that on those portions of the ground plane not directly illuminated by the glide slope array (shadowed regions), $\vec{K}$ is identically zero and that on those portions of the ground which are illuminated, $\vec{K}$ is given by twice the tangential component of the incident magnetic field

$$\vec{K} \equiv 0 \text{ on } S_-; \tag{5}$$

$$\vec{K} = 2(\hat{n} \times \vec{H}_i) \text{ on } S_+, \tag{6}$$

where S_- and S_+ denote, respectively, the unilluminated and illuminated portions of the ground plane S. The physical optics approximation for the current distribution should be reasonably accurate when the characteristic dimensions of the terrain irregularities are large compared with the wavelength λ. Substituting equations (5) and (6) into equation (3), we obtain the following approximate expression for the ground-reflected magnetic field at the receiver point $\vec{r}_1$:

$$\vec{H}_s(\vec{r}_1) = \frac{1}{2\pi} \int_{S_+} [\hat{n}(\vec{r}) \times \vec{H}_i(\vec{r})] \times \vec{\nabla} G(\vec{r}_1, \vec{r}) ds. \tag{7}$$

The numerical evaluation of the integral in Equation (7) for a ground plane exhibiting arbitrary terrain variations is, in general, a prohibitively time-consuming operation. Consequently, we will confine our attention to terrains which vary only along one coordinate axis. Specifically, we will treat ground planes which exhibit irregularities which do not vary in the direction perpendicular to the centerline of the runway. The touchdown point on the centerline of the runway opposite the glide slope array will be chosen as the origin of coordinates. The z-axis is chosen to be the vertical axis passing through the origin O and pointing out of the ground while the x- and y-axes lie in a horizontal plane whose normal parallels the z-axis. The x-axis points along the centerline of the runway while the y-axis is perpendicular to the centerline. The terrain irregularities are assumed to vary only with x.

That is to say, the equation of the surface of the ground is of the form $z = f(x)$ and is independent of variations in y. To put it another way, the local outward normal to the ground, $\hat{n}$, has only x and z components.

We will now consider the problem of a horizontal dipole mounted above such a ground plane and oriented parallel to the y-axis, the invariant axis of the terrain irregularities. The geometry of a typical problem is illustrated in Figure 1. The y-axis points into the page and the entire ground plane can be generated by projecting the cross section depicted in Figure 1 from $-\infty$ to $+\infty$ in the y-direction.

To calculate the scattered field $\vec{H}_s$, generated by a given terrain contour, the ground plane is first divided into a number of connected planar sections which extend from $-\infty$ to $+\infty$ in the y-direction. The side view of such a section is represented by the darkened segment of the contour depicted in Figure 1. The points (x_{01},z_{01}) and (x_{02},z_{02}) represent the end points of the section. The length L of a given segment

$$\left(L = \sqrt{(x_{02}-x_{01})^2 + (z_{02}-z_{01})^2}\right)$$

is so chosen that the unit normal $\hat{n}$ is essentially constant for $z_{01} \leq z \leq z_{02}$ and $x_{01} \leq x \leq x_{02}$. Once the contour has been segmented into these planar sections, Equation (7) can be applied to each section and the total scattered field $\vec{H}_s$ can be obtained by summing the contributions from all the sections. We will therefore concentrate upon obtaining an expression for the contribution to the total scattered field $\vec{H}_s$ from a typical planar segment such as the one depicted in Figure 1. It will be assumed that only those segments which are in front of the receiver ($-\infty < x \leq x_1$) contribute to $\vec{H}_s$. The terrain behind the dipole ($-\infty \leq x \leq 0$) is assumed to be perfectly flat. The exact nature of terrain behind the antenna is not really critical since, in practice, the dipoles which make up glide slope arrays are screened to eliminate the back course.

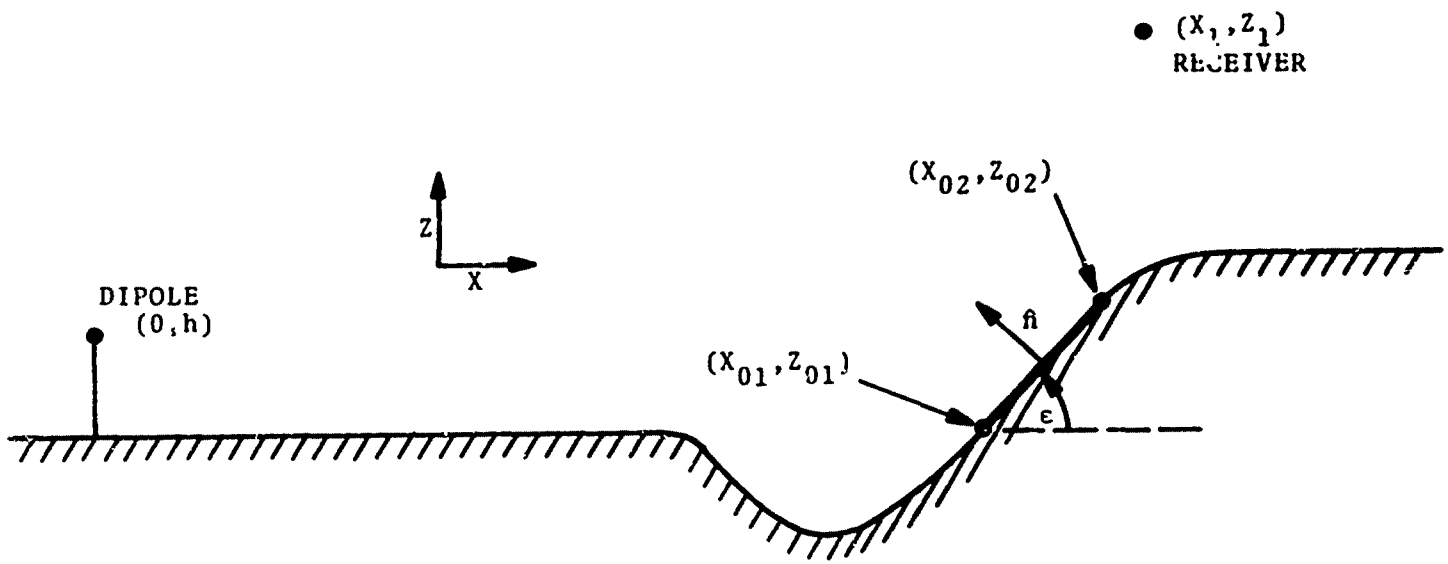


Figure 1. Geometry of a Typical One-Dimensional Ground Reflection Problem

Let $\vec{h}_s$ denote the contribution to the total scattered field from the planar section shown in Figure 1:

$$\vec{h}_s(\vec{r}_1) = \frac{1}{2\pi} \int [\hat{n} \times \vec{H}_i(\vec{r})] \times \vec{\nabla} G(\vec{r}_1, \vec{r}) ds \qquad (8)$$

where the integral is carried out over the surface of the segment (cf. Eq. (7)). Let $\hat{e}_x$, $\hat{e}_y$, and $\hat{e}_z$ denote, respectively, the unit vectors in the x, y, and z directions. In terms of these vectors, the unit normal n is given by:

$$\hat{n} = -\sin\varepsilon\, \hat{e}_x + \cos\varepsilon\, \hat{e}_z, \qquad (9)$$

where ε is the angle between the planar section and the x-axis (cf. Fig. 1). The (x,z) coordinates of the transmitting dipole and the receiver are denoted, respectively, by (0,h) and (x_1, z_1). For simplicity, we will assume that the receiver is on the centerline of the runway so that $y_1 = 0$. The y-displacement of the dipole will be denoted by y_a. Glide slope arrays are generally located several hundred feet from the centerline of the runway.

The incident magnetic field $\vec{H}_i(\vec{r})$ produced by the transmitting dipole is given in terms of the volume current density $\vec{J}$ in the dipole by the following formula:

$$\vec{H}_i(\vec{r}) = \frac{1}{4\pi} \int \left(\vec{J}(\vec{r}') \times \vec{\nabla}' G(\vec{r}, \vec{r}') \right) dv', \qquad (10)$$

where $\vec{\nabla}'$ operates on the primed coordinates. Although the actual dipoles which make up glide slope arrays are half-wavelength bent dipoles, we will treat the case of a point dipole with the following volume current distribution:

$$\vec{J}(\vec{r}') = J_0\, \hat{e}_y\, \delta(x')\, \delta(y' - y_a)\, \delta(z' - h). \qquad (11)$$

This simplifying assumption expedites the evaluation of the integrals (10) and (8) and should not be too restrictive since we are only interested in the vertical radiation pattern formed by the direct and ground reflected radiation. In Equation (11), J_0 is some constant, the δ-functions are the Dirac delta functions, and, as previously noted, y_a and h denote, respectively, the displacement of the dipole from the centerline of the runway and the height of the antenna above ground.

Substituting Equation (11) into Equation (10) and integrating, we obtain the following expression for the incident magnetic field $H_i(r)$:

$$\vec{H}_i(\vec{r}) = i\frac{kJ_o}{4\pi}\ \frac{e^{ikD}}{D}\ f(D)\ [x\ \hat{e}_z - (z-h)\hat{e}_x], \qquad (12)$$

where $\vec{r} = x\ \hat{e}_x + y\ \hat{e}_y + z\ \hat{e}_z$ and D is the distance from the antenna to the field point $\vec{r}$:

$$D = [x^2 + (y-y_a)^2 + (z-h)^2]^{1/2}. \qquad (13)$$

The function f(D) is given by

$$f(D) = \frac{1}{D} + \frac{i}{kD^2}. \qquad (14)$$

It will be noted from the form of f(D) that we are retaining the near field as well as the far field contributions to $\vec{H}_i$.

Equations (9) and (12) can now be substituted into Equation (8), and the magnetic field $\vec{h}_s$ at the receiver point $\vec{r}_1 = x_1\ \hat{e}_x + z_1\ \hat{e}_z$, due to the single planar section of terrain, evaluated. We will assume that the receiver is in the far field of the terrain segment so that $\vec{\nabla} G(\vec{r}_1,\vec{r})$ can be written as follows:

$$\vec{\nabla}G(\vec{r}_1,\vec{r}) \simeq -ik\ \frac{(\vec{r}_1-\vec{r})}{|\vec{r}_1-\vec{r}|}\ \frac{e^{ik|\vec{r}_1-\vec{r}|}}{|\vec{r}_1-\vec{r}|}. \qquad (15)$$

Actually, only the z-component of $\vec{h}_s$ need be calculated since the receiving antenna responds primarily to this component (equivalently, the horizontal component of the electric field). The z-component of $\vec{h}_s$ will be denoted by h_{sz}. Substituting Equations (9), (12), and (15) into Equation (8), we obtain the following expression for h_{sz} at the receiver:

$$h_{sz}(\vec{r}_1) = -\frac{k^2 J_0}{8\pi^2}\int\frac{(x_1-x)(x\sin\varepsilon - (z-h)\cos\varepsilon)f(D)e^{ik(D+R)}}{DR^2}\ ds, \qquad (16)$$

where $R = [(x_1-x)^2 + y^2 + (z_1-z)^2]^{1/2}$ is the distance from a point

on the terrain segment to the receiver. The element of area ds is equal to dydη, where η is a variable ranging from 0 to L along the surface of the terrain segment perpendicular to the y-axis. The x- and z-coordinates of a point on the surface of the planar section can be expressed in terms of η as follows (cf. Fig. 1):

$$\begin{aligned} x &= x_{01} + \eta \cos\varepsilon, \quad 0 \le \eta \le L \\ z &= z_{01} + \eta \sin\varepsilon, \quad 0 \le \eta \le L \end{aligned} \qquad (17)$$

Substituting Equations (17) into Equation (16), we obtain

$$h_{sz}(\vec{r}_1) = \frac{k^2 J_o}{8\pi^2}[(z_{01}-h)\cos\varepsilon - x_{01}\sin\varepsilon] \; X$$

$$\int_0^L \int_{-\infty}^{+\infty} \frac{(x_1 - x_{01} - \eta\cos\varepsilon)}{DR^2} f(D)\, e^{ik(D+R)} dy d\eta, \qquad (18)$$

where D and R are expressed as functions of the variables y and η as follows:

$$D = [(x_{01}+\eta\cos\varepsilon)^2 + (y-y_a)^2 + (z_{01}-h+\eta\sin\varepsilon)^2]^{1/2}, \qquad (19)$$

$$R = [(x_1 - x_{01} - \eta\cos\varepsilon)^2 + y^2 + (z_1 - z_{01} - \eta\sin\varepsilon)^2]^{1/2}. \qquad (20)$$

The integration with respect to $y(-\infty<y<+\infty)$ can be performed approximately using the method of stationary phase leaving only an integral with respect to η to be evaluated numerically:

$$h_{sz}(\vec{r}_1) = \frac{k^2 J_0}{8\pi^2} [(z_{01}-h)\cos\varepsilon - x_{01}\sin\varepsilon]\lambda^{1/2} e^{i\,\pi/4}\, I, \qquad (21)$$

where

$$I = \int_0^L e^{ikF(\eta)} G(\eta) d\eta, \qquad (22)$$

and F and G are defined as follows:

$$A = [(x_1 - x_{0i} - r\cos\varepsilon)^2 + (z_1 - z_{01} - \eta\sin\varepsilon)^2]^{1/2},$$

$$B = [(x_{01} + \eta\cos\varepsilon)^2 + (z_{01} - h + \eta\sin\varepsilon)^2]^{1/2},$$

$$C = \left[1 + \frac{y_a^2}{(A+B)^2}\right]^{1/2}, \quad D = CB, \quad R = CA,$$

$$S = \frac{1}{C^3}\left[\frac{1}{A} + \frac{1}{B}\right],$$

$$F(\eta) = C(A + B),$$

$$G(\eta) = \frac{f(D)\ [x_1 - x_{01} - \eta\cos\varepsilon]}{DR^2 S^{1/2}}. \qquad (23)$$

The contribution to the total scattered field $\vec{H}_s$ from the region behind the antenna ($-\infty<x\leq 0$) can be calculated approximately using asymptotic methods. As noted previously, the terrain behind the glide slope array is assumed to be perfectly flat ($\varepsilon=0$, $z=0$ for $-\infty<x\leq 0$). From Equation (16), the contribution to H_{sz} from this back course region, which will be denoted by $\hat{h}_{sz}$, can be written as follows:

$$\hat{h}_{sz}(\vec{r}_1) = \frac{-k^2 h J_0}{8\pi^2}\int_{-\infty}^{0}\int_{-\infty}^{+\infty}(x_1 - x)\ \frac{f(D)}{DR^2}\ e^{ik(D+R)}dydx, \qquad (24)$$

where

$$D = [x^2 + (y - y_a)^2 + h^2]^{1/2}, \qquad (25)$$

and

$$R = [(x_1 - x)^2 + y^2 + z_1^2]^{1/2}. \qquad (26)$$

As before, the y-integration is performed by the method of stationary phase leaving an integral of the following form:

$$\hat{h}_{sz}(\vec{r}_1) = \frac{-k^2 h J_0 \lambda^{1/2} e^{i\pi/4}}{8\pi^2}\int_{-\infty}^{0} e^{ikF_1(x)}\ G_1(x)dx, \qquad (27)$$

where F_1 and G_1 are defined as follows:

$$A_1 = [(x_1-x)^2 + z_1^2]^{1/2},$$

$$B_1 = [x^2 + h^2]^{1/2},$$

$$C_1 = 1 + \left[\frac{y_a^2}{(A_1+B_1)^2}\right]^{1/2}, \quad D = CB_1, \quad R = CA_1,$$

$$S_1 = \frac{1}{C_1^3}\left[\frac{1}{A_1} + \frac{1}{B_1}\right]$$

$$G_1(x) = \frac{f(D)}{D}\,\frac{[x_1-x]}{R^2\,S_1^{1/2}}\,.$$

$$F_1(x) = C_1\,(A_1 + B_1)$$

Integrals of the type in Equation (27) with rapidly varying phase functions and no stationary points in the range of integration (here $-\infty<x\leq 0$) can be approximated very accurately using asymptotic techniques. It turns out that the major contribution to the integral in (27) comes from the vicinity of $x = 0$ and that we can write to a very good approximation:

$$\bar{h}_{sz}(\vec{r}_1) = \frac{ikhJ_0\lambda^{1/2}e^{i\pi/4}}{8\pi^2}\,\frac{G_1(0)e^{ikF_1(0)}}{F_1'(0)}\,, \qquad (28)$$

where $G_1(0)$, $F_1(0)$, and $F_1'(0)$ denote, respectively the values of G_1, F_1, and the first derivative of F_1 at $x = 0$. These quantities are defined below:

$$A_1(0) = [x_1^2 + z_1^2]^{1/2}$$

$$B_1(0) = h$$

$$C_1(0) = \left[1 + \frac{y_a^2}{(A_1(0)+B_1(0))^2}\right]^{1/2}$$

$$D(0) = C_1(0)B_1(0)$$

$$R(0) = C_1(0)A_1(0)$$

$$S_1(0) = \frac{1}{C_1^3(0)}\left[\frac{1}{A_1(0)} + \frac{1}{B_1(0)}\right]$$

$$F_1(0) = C_1(0)\,[A_1(0) + B_1(0)]$$

$$G_1(0) = \frac{f(D(0))x_1}{D(0)R^2(0)S_1^{1/2}(0)}$$

$$F_1'(0) = \frac{-[A_1(0)+B_1(0)]}{F_1(0)}\,\frac{x_1}{A_1(0)}\,. \qquad (29)$$

Using Equation (28) to represent the contribution to the total scattered field from the region behind the antenna and applying Equation (21) to each illuminated terrain segment lying between the dipole and the receiver, we obtain the total z-component of the scattered magnetic field by summing all these contributions:

$$H_{sz} = \bar{h}_{sz} + \sum h_{sz}. \qquad (30)$$

The procedure for calculating the difference in depth of modulation (DDM) at a given receiver location is quite straightforward. First, using the procedure outlined above, the complex field amplitudes at the receiver due to each element in the glide slope array are calculated. Let H_c, H_{150}, and H_{90} denote the total complex field amplitudes (direct plus scattered summed for all dipoles in the array) at the carrier frequency, the 150 Hz modulated frequency, and 90 Hz modulated frequency, respectively. In terms of these complex amplitudes, the difference in depth of modulation is given by:

$$D.D.M. = \mathrm{Re}\left(\frac{H_{150}-H_{90}}{H_c}\right), \qquad (31)$$

where Re denotes the real part of the complex number. Full scale deflection (150 microamperes) corresponds to a D.D.M. of .175 for the glide slope. Consequently, the C.D.I. (course deviation indication) is given by:

$$C.D.I. = 857.14\ \mathrm{Re}\left(\frac{H_{150}-H_{90}}{Hc}\right). \qquad (32)$$

3. NUMERICAL RESULTS

3.1 INTRODUCTION

The formalism developed in the preceding section has been applied to a whole series of glide slope siting problems. All three main types of image glide slope arrays (null reference, sideband reference, capture effect) have been treated. Comparative results will be presented illustrating the performance of each array for a few terrain configurations suggested to us for study by the FAA.

The null reference array is the simplest of the image glide slope systems. It consists of two transmitting antennas whose heights are in the ratio of 2:1. The upper antenna is fed sideband only signal, the 150 Hz and the 90 Hz components being of equal amplitude but 180° out of phase. The lower antenna is fed both carrier and sideband. The carrier signal is nominally 40% modulated. The ratio of the sideband currents in the upper antenna to the sideband currents in the lower antenna is typically 0.3. The sideband ratio of 0.3 would nominally yield a 1.4° course width (full deflection 0.7° above or below the glide path). Let I_c, I_{150}, and I_{90} denote the current amplitudes fed to the antennas at the carrier frequency, the 150 Hz modulated frequency, and the 90 Hz modulated frequency, respectively. The null reference array parameters discussed above can be summarized as follows:

Carrier Antenna	Sideband Antenna
Height = h	Height = 2h
$I_c = 1$	$I_c = 0$
$I_{150} = 0.4$	$I_{150} = 0.12$
$I_{90} = 0.4$	$I_{90} = -0.12$

Note that all current amplitudes have been normalized relative to the carrier current amplitude ($I_c = 1$).

The sideband reference array employs two transmitting dipoles whose heights are in the ratio of 3:1. If the lower antenna is positioned at 1/2 the height of the lower antenna of the null

reference array and if the upper antenna is positioned at 3/4 of the height of the upper antenna of the null reference array, the same glide angle is produced. Modulated carrier (40% modulated) is fed to the lower antenna. Both antennas are fed separate sideband signal. The separate sideband signals fed to the two antennas are equal in amplitude but are 180° out of phase. The amplitude ratio of the separate sideband signal to the carrier sideband signal is typically 0.3. This ratio produces a nominal course width of 1.4° as in the case of the null reference array. The sideband reference parameters are summarized below.

Lower Antenna	Upper Antenna
Height = h	Height = 3h
$I_c = 1$	$I_c = 0$
$I_{150} = 0.28$	$I_{150} = 0.12$
$I_{90} = 0.52$	$I_{90} = -0.12$

Note that the I_{150} and I_{90} current amplitudes given above for the lower antenna represent the sums of the carrier sideband and separate sideband signals ($I_{150} = .4-.12 = .28$, $I_{90} = .4+.12 = .52$). All current amplitudes have been normalized relative to the carrier signal amplitude.

The capture effect glide slope array consists of three transmitting antennas whose heights are in the ratios of 1:2:3. If the lower and middle antennas are set at the same heights as the null reference antennas, the same glide angle is produced. We will not treat the clearance signal which provides a strong fly up signal at low approach angles but has little effect upon the glide angle and course width. Concerning the primary signal, modulated carrier is fed to both the lower and the middle antennas. The modulated carrier fed to the middle antenna has half the amplitude and is 180° out of phase with the modulated carrier fed to the lower antenna. The carrier signals are nominally 40% modulated. In addition, all three antennas are fed separate sideband signal. The separate sideband signals fed to the lower and upper antennas have half the amplitude and are 180° out of phase with the separate sideband signal fed to

the middle antenna. The ratio of the separate sideband signal fed to the middle antenna to the carrier sideband signal in the lower antenna is typically 0.3. This ratio yields nominally a course width of 1.4° as in the case of the null reference array. The capture effect array parameters are summarized below.

Lower Antenna	Middle Antenna
Height = h	Height = 2h
$I_c = 1$	$I_c = -0.5$
$I_{150} = 0.34$	$I_{150} = -0.08$
$I_{90} = 0.46$	$I_{90} = -0.32$

Upper Antenna

Height = 3h
$I_c = 0$
$I_{150} = -0.06$
$I_{90} = 0.06$

Note that the I_{150} and I_{90} current amplitudes given above represent the sums of the carrier sideband and separate sideband signals. Again, all values have been normalized relative to the carrier amplitude in the lower antenna.

It should be noted here that our computer program automatically offsets the elements of each glide slope array to correct for the effects of proximity phase lag. The y coordinates of the elements are adjusted so that all dipoles are at the same slant distance from the touchdown point on the runway directly opposite the array. For each array, one element is held fixed while the other elements are offset relative to the fixed one. For the null reference and sideband reference arrays, the lower element is held fixed while for the capture array, the middle element is held fixed. The amount of the offset for each dipole can be calculated approximately in the following manner. Let y_a and h denote, respectively, the y-coordinate and height of the fixed antenna element. The y-displacement, ε, of any other element in the array relative to the fixed one is given approximately by:

$$\varepsilon = \frac{h^2 - H^2}{2y_a} \qquad (33)$$

where H is the height of the element which is to be offset.

For the present study, the wavelength λ was set at 3 feet. All arrays were positioned 400 feet from the centerline of the runway. The heights of the array elements were set at 14.33 feet and 28.66 feet (approximately 5λ and 10λ) for the null reference array, 7.17 feet and 21.5 feet (approximately 2.5λ and 7.5λ) for the sideband reference array, and 14.33 feet, 28.66 feet, and 42.99 feet (approximately 5λ, 10λ, and 15λ) for the capture effect array. If the ground plane were perfectly flat, a glide angle of 3° would be produced by all three arrays.

Two types of data will be presented. CDI as a function of horizontal distance from touchdown will be plotted for an aircraft in level flight at an altitude of 1200 feet as measured from the base of the antenna array (z_1 = 1200 ft.). This horizontal flight data is useful for studying course linearity. In addition, CDI as a function of horizontal distance from touchdown will be plotted for an aircraft flying the nominal 3° glide path. On the graphs to be presented, positive CDI indicates that the 150 Hz modulation is dominant (fly up indication) while negative CDI indicates that the 90 Hz modulation is dominant (fly down indication).

3.2 FLAT TERRAIN

Figures 2 and 2A show the level flight and nominal glide path CDI for the null reference array assuming a perfectly flat ground plane. The data was generated by summing the contributions to the scattered field from the first 5000 feet of ground plane. The results for all three arrays are essentially identical in this case so that we will present only the null reference data. The dashed lines in the figures represent the ideal results which are based upon simple image theory assuming a flat, infinite ground plane. The ideal results and the predictions of our model are clearly in close agreement. Obviously, 5000 feet of flat ground are quite sufficient to produce an excellent course. The small discrepancies between the ideal results and the predictions of our

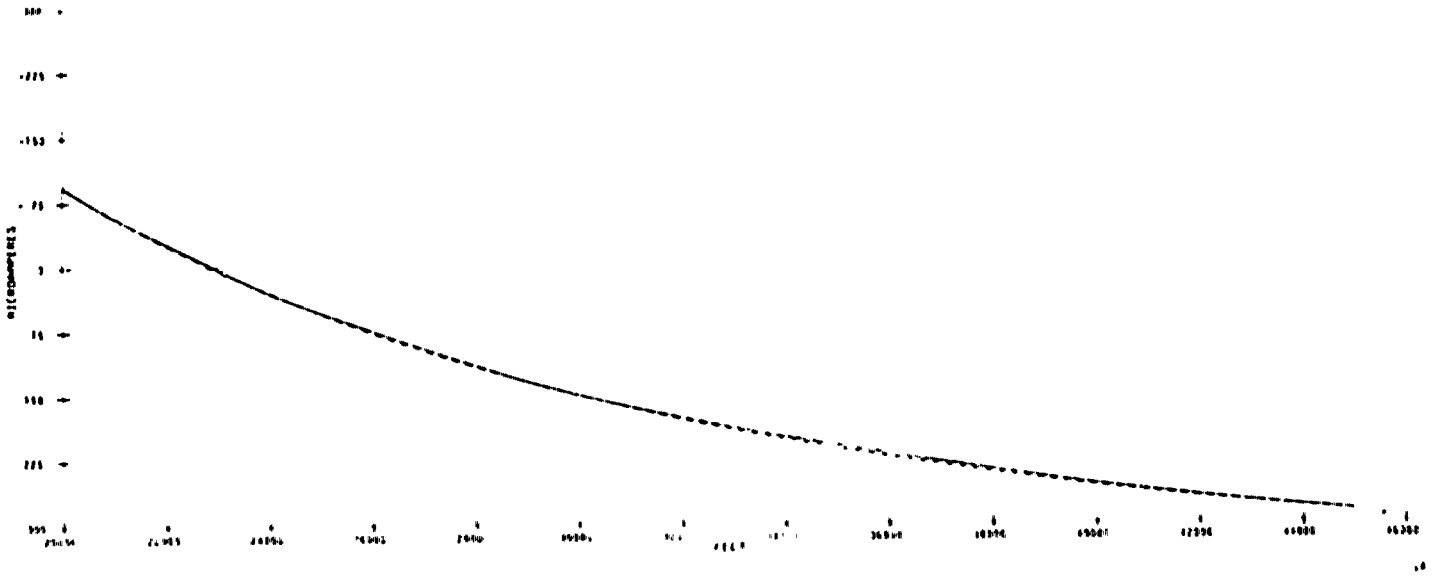


Figure 2. Null Reference Array, Level Run Flight, Flat Terrain

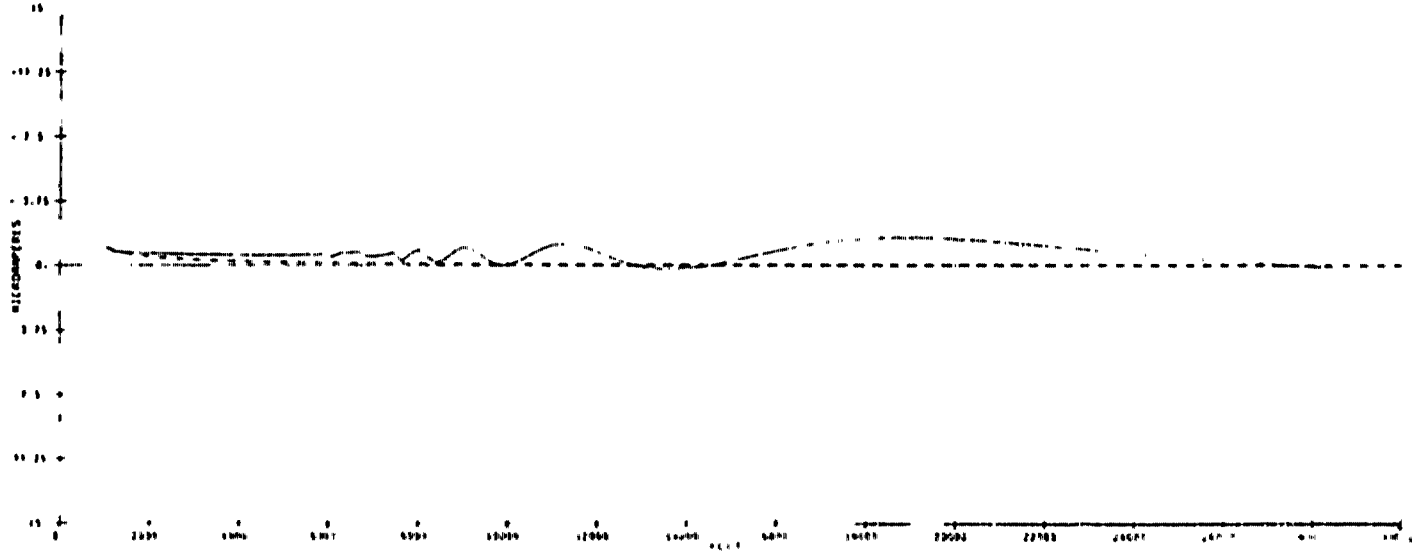


Figure 2A. Null Reference Array, Flyability Run, Flat Terrain

model which are most apparent in Figure 2A result from the truncation of the ground. These deviations however amount to, at most, approximately 2 microamps. Figure 2A shows a perfect flare or hyperbola being flown as would appear in a standard radio theodolite flight inspection run. (Had a straight line glide path at 3° been flown, the CDI would have assumed larger and larger positive values (fly up indication) as the receiver approached the touchdown point due to the fact that the straight line glide path is actually only asymptotic to and actually below the true zero DDM trajectory which is a hyperbola.)

3.3 TERRAIN DISCONTINUITY

The next series of graphs (Figs. 3A, 3B, 3C, 3D, 3E, 3F) give the predictions of our model for a terrain which slopes downward away from the array for 1200 feet at an angle of 0.6° from the horizontal and then levels off for an additional 3800 feet at which point we truncate the ground plane (see Fig. 3). The dashed lines represent the ideal image theory predictions based upon the infinite, flat ground plane. The results for all three arrays (null reference, sideband reference, and capture effect) are very similar. The courses undergo a downward shift of 0.6° relative to the horizontal.

Referring to the level run flight data (Figs. 3A, 3B, 3C), it will be noted that the zero crossings occur at approximately 29,500 feet from touchdown. For a receiver at a height of 1200 feet as measured from the base of the antenna array (z_1 = 1200 ft.), the zero crossing at 29,500 feet would indicate a glide angle of approximately 2.33° relative to the horizontal (the x-y plane). The nominal glide angle is 3°.

The flyability runs (Figs. 3D, 3E, 3F) also reflect this downward shift. Flying the nominal 3° glide path, the data shows a nearly constant fly down indication of between 111 and 140 microamperes. Assuming a course width of 1.4° (0.7° above or below the glide path corresponding to full scale deflection of 150 microamperes), fly down signals in this range indicate that the receiver is about 0.6° above the true glide angle.

Figure 3. Terrain Discontinuity

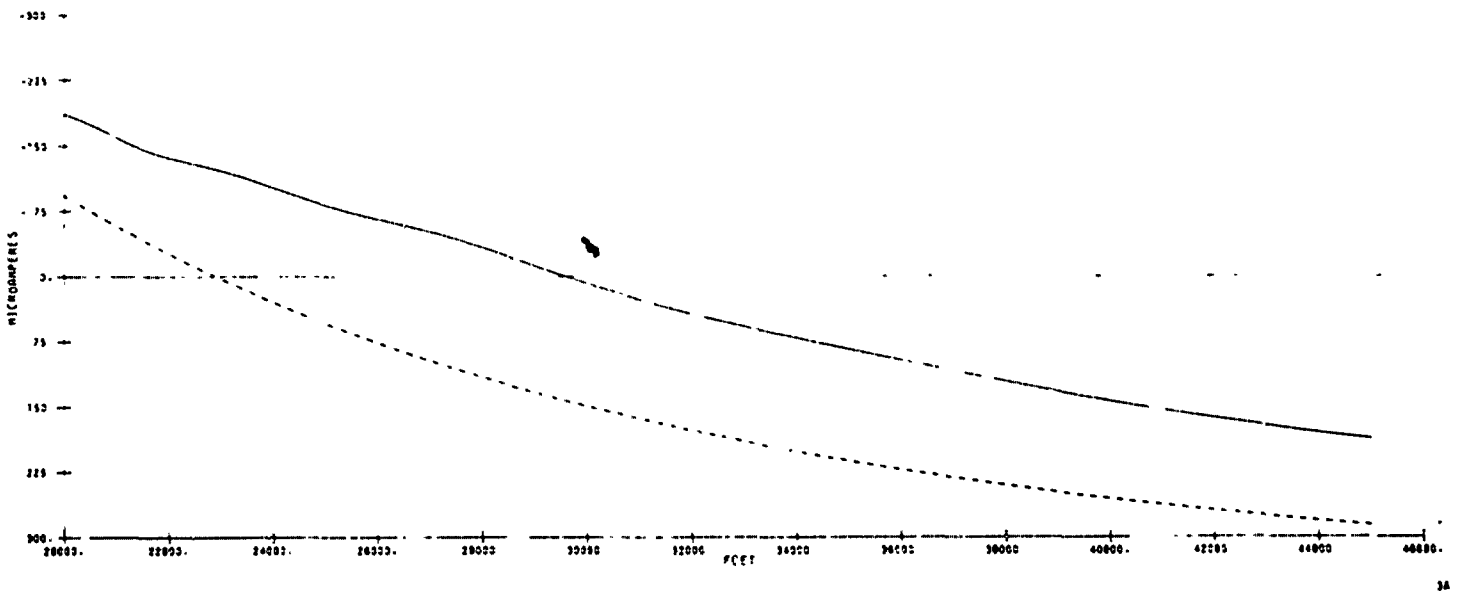


Figure 3A. Null Reference Array, Level Run Flight, Terrain Discontinuity

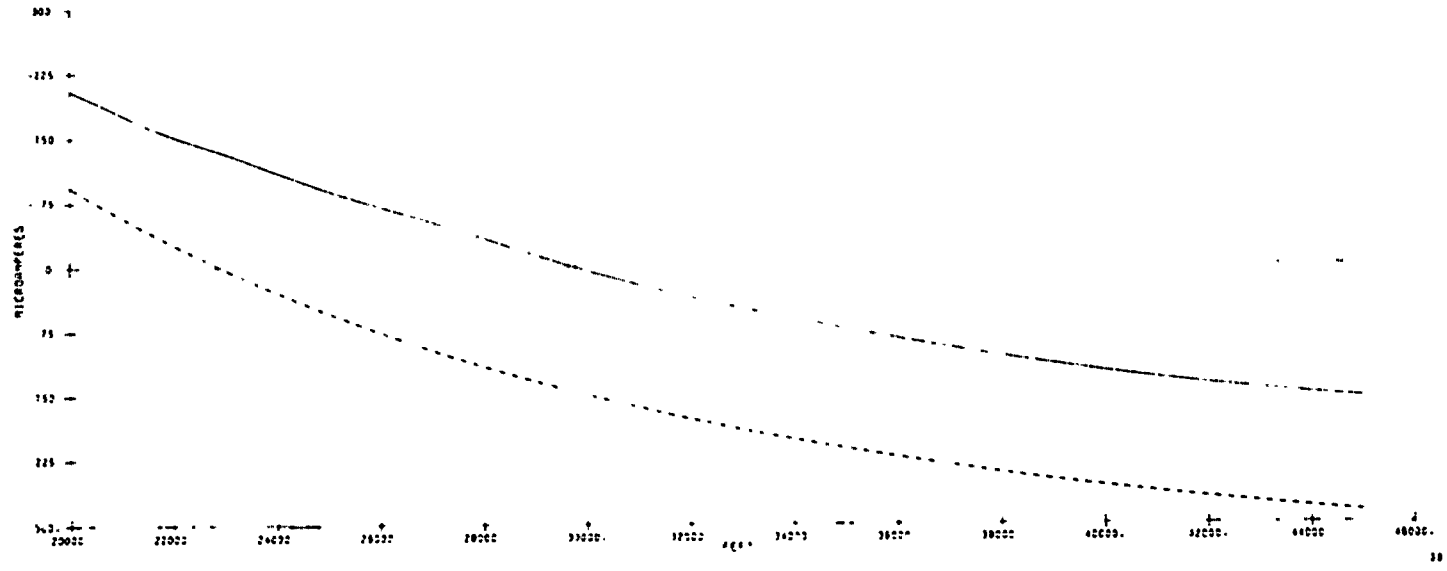


Figure 3B. Sideband Reference Array, Level Run Flight, Terrain Discontinuity

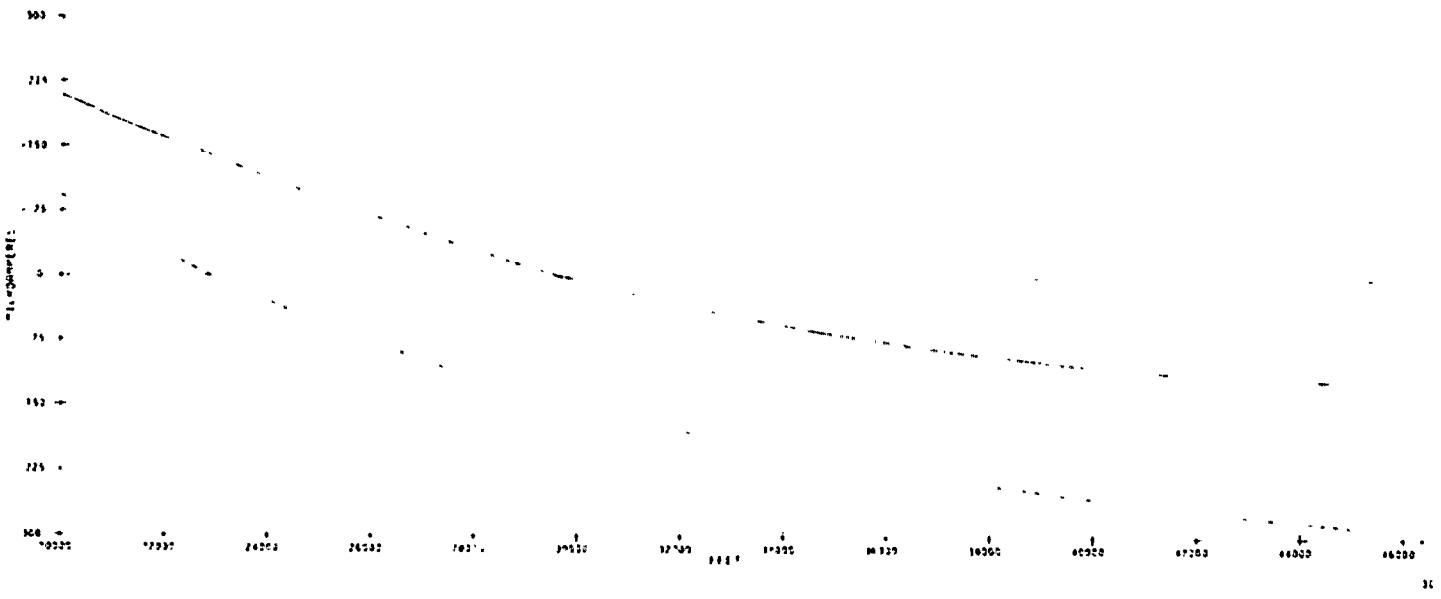


Figure 3C. Capture Effect Array, Level Run Flight, Terrain Discontinuity

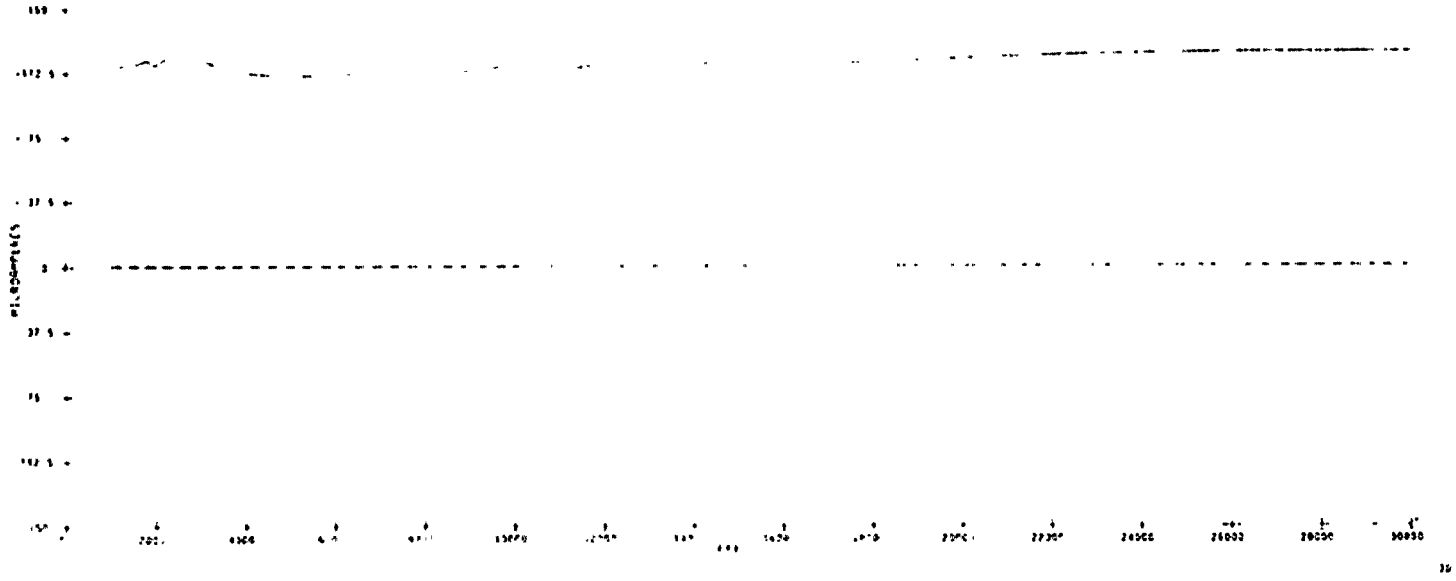


Figure 3D. Null Reference Array, Flyability Run, Terrain Discontinuity

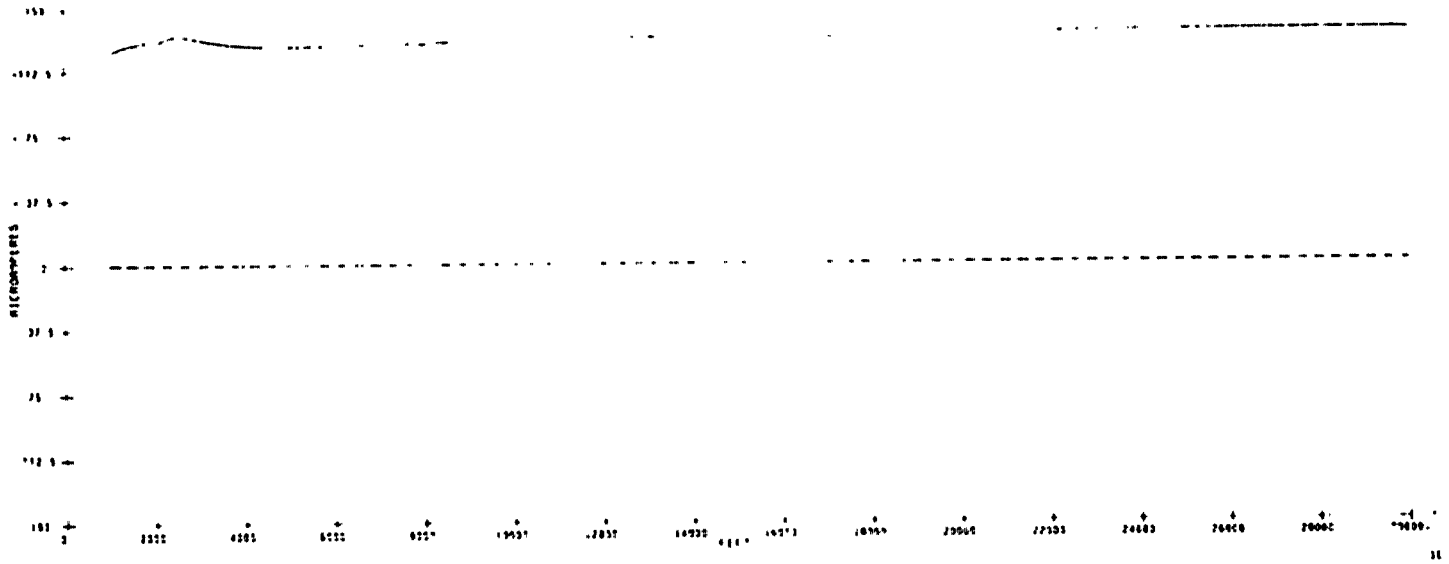


Figure 3E. Sideband Reference Array, Flyability Run, Terrain Discontinuity

Figure 3F. Capture Effect Array, Flyability Run, Terrain Discontinuity

3.3.1 Adjusted Antenna Element Heights

In order to correct for this downward shift of the glide path angle, the antenna array elements have been repositioned downwards to give a 3° glide path angle. This glide path angle is determined as the arithmetical mean over the distance between the middle marker (3500 feet from the threshold) and four miles from the threshold along the runway centerline extended.

The null reference, sideband reference and capture effect antenna element re-positioning are shown in Table 1.

TABLE 1.

	Original Positions (feet)			New Positions (feet)		
	Lowest	Middle	Highest	Lowest	Middle	Highest
Null Reference	14.33		28.66	11.99		23.97
S.B. Reference	7.17		21.5	5.88		17.64
Capture Effect	14.33	28.66	42.99	11.66	23.32	34.97

The level flight results with these new antenna element positioning are shown in Figures 3G, 3H, and 3I. The crossovers occur very nearly at the nominal glide angle of 3° (which for the 1200 foot high horizontal flight corresponds to approximately 22,900 feet on the abcissa of the graph).

The flyability run results with this new positioning are shown in Figures 3J, 3K, and 3L. For all three antennas, the CDI has been reduced to just a few microamperes by the above repositioning of the antenna element heights.

3.4 20-FOOT DROPOFF

The next series of graphs (Figs. 4A, 4B, 4C, 4D, 4E, 4F) show the results for a terrain which extends flat for 1200 feet in front of the array and then drops off 20 feet to a lower plateau which then extends outward an additional 3800 feet (see Fig. 4). From Figures 4A and 4D, it can be seen that the null reference course tends to be elevated in the presence of such a terrain.

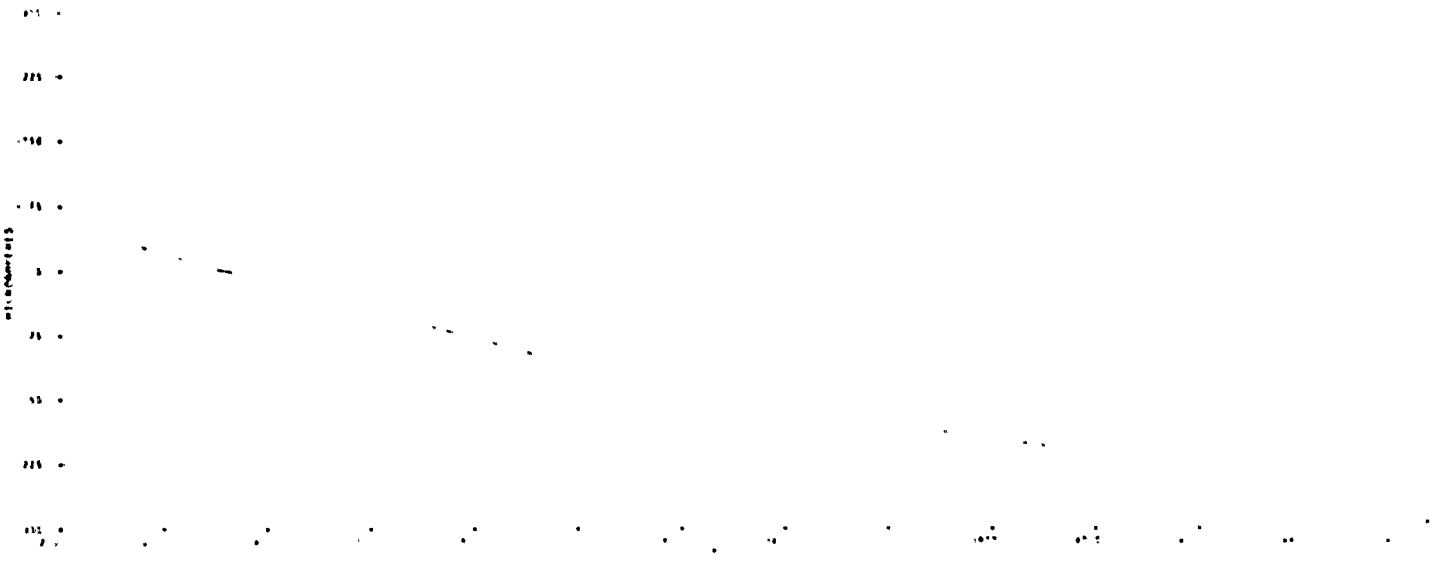


Figure 3G. Adjusted Null Reference Array, Level Run Flight, Terrain Discontinuity

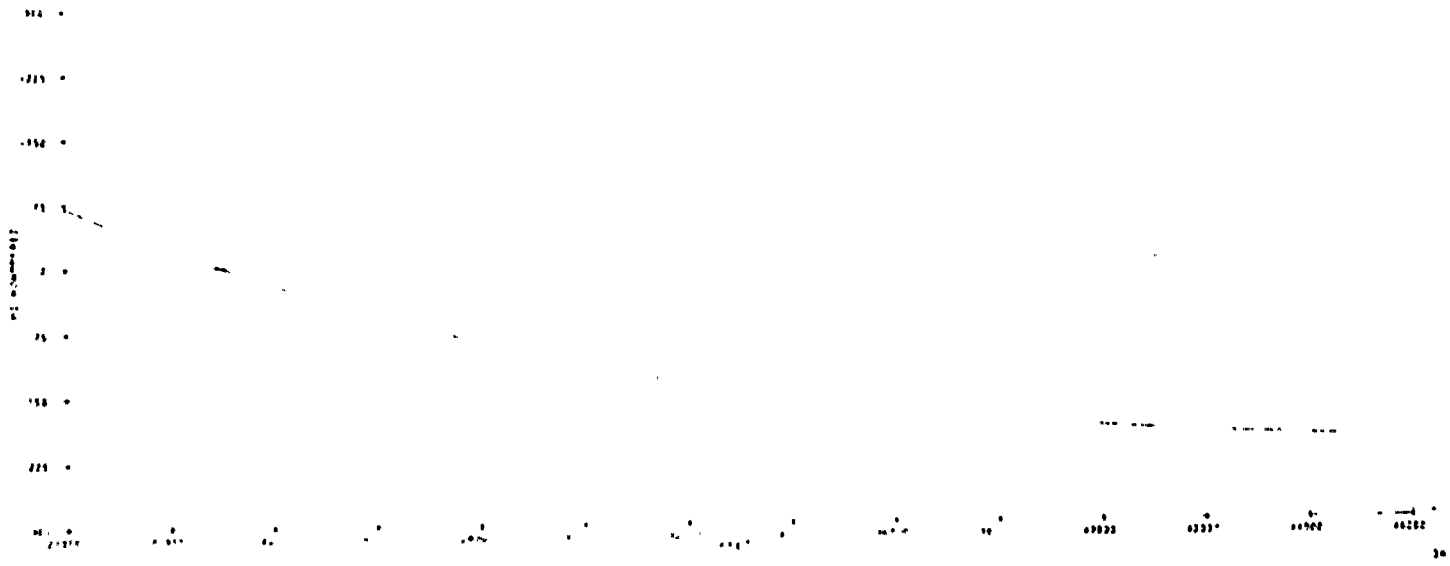


Figure 311. Adjusted Sideband Reference Array, Level Run Flight, Terrain Discontinuity

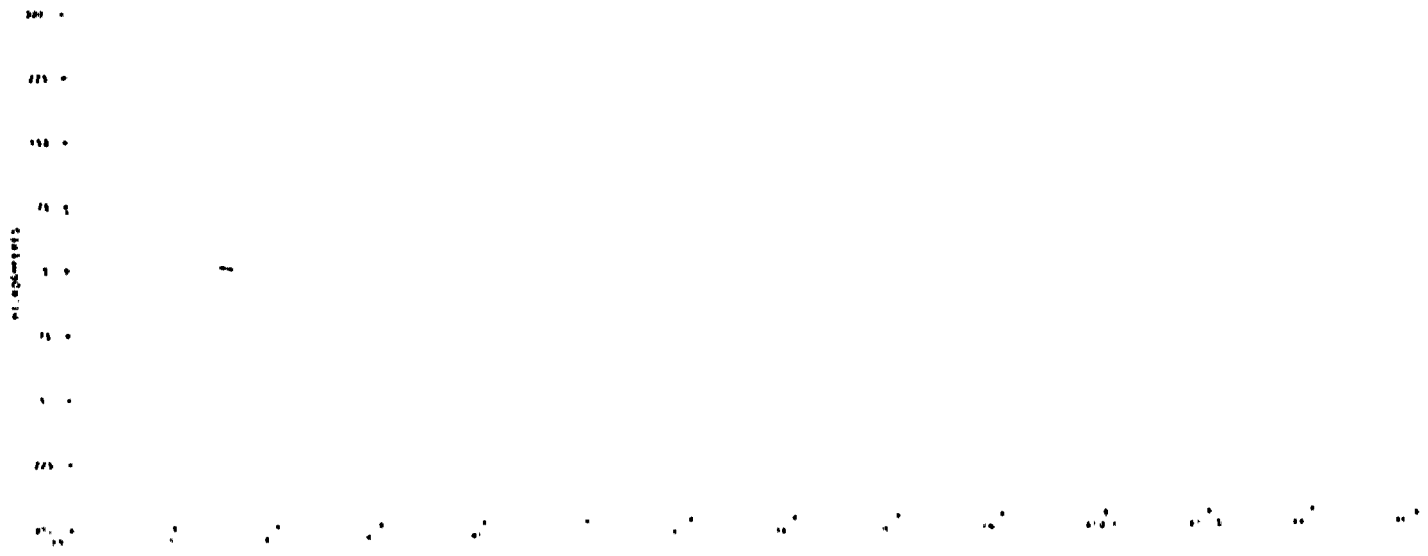


Figure 31. Adjusted Capture Effect Array, Level Run Flight, Terrain Discontinuity

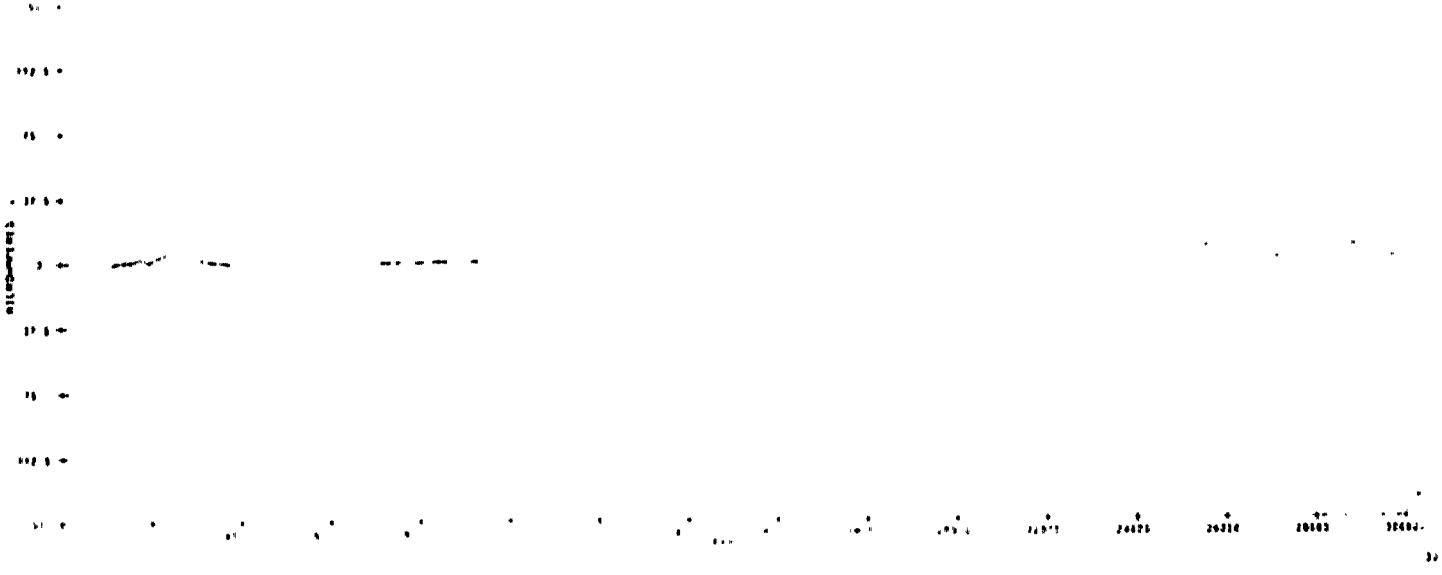


Figure 3J. Adjusted Null Reference Array, Flyability Run, Terrain Discontinuity

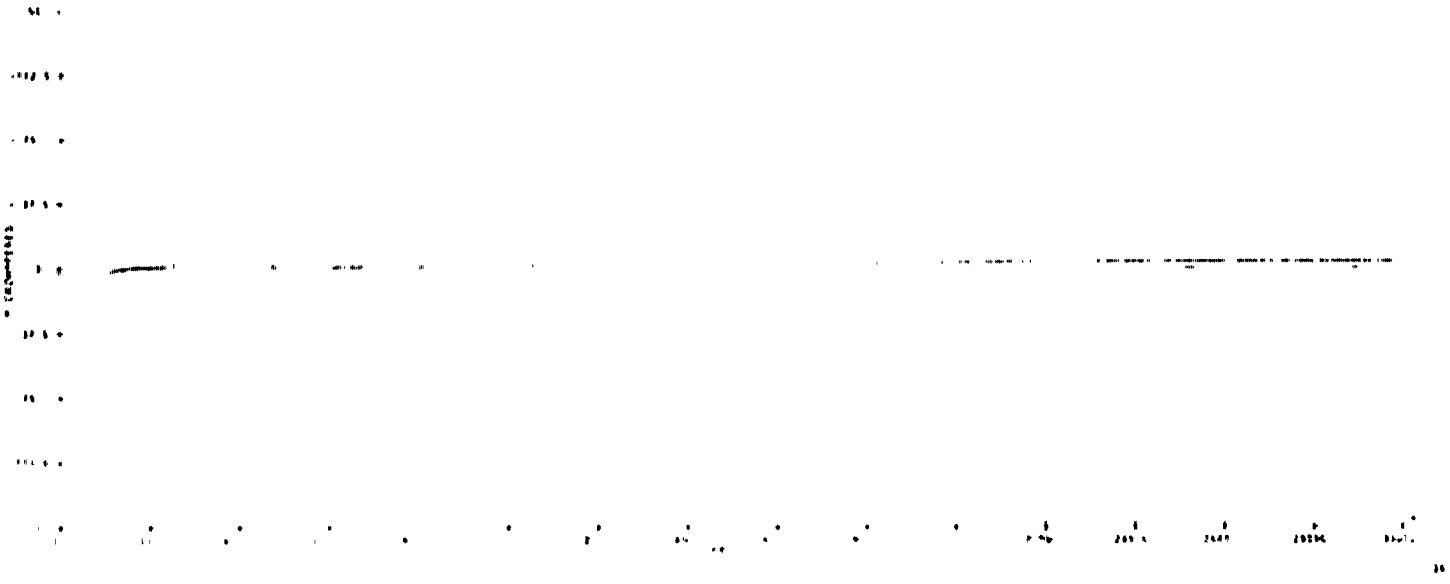


Figure 3K. Adjusted Sideband Reference Array, Flyability Run, Terrain Discontinuity

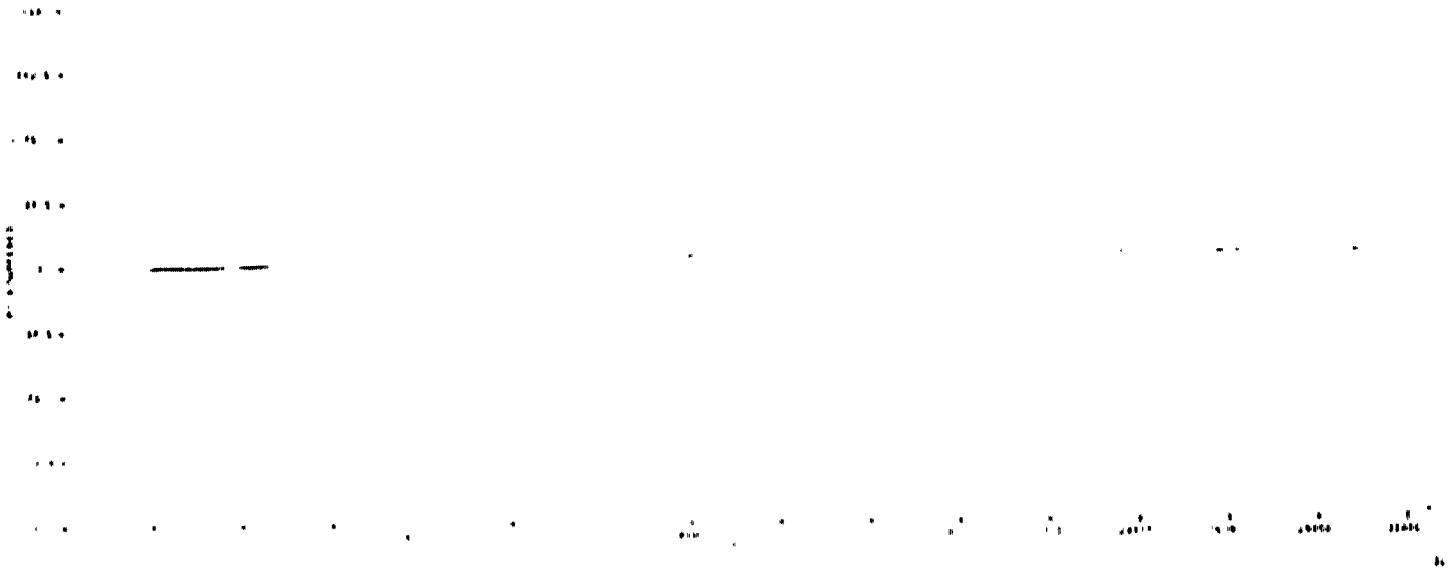


Figure 31. Adjusted Capture Effect Array, Flyability Run, Terrain Discontinuity

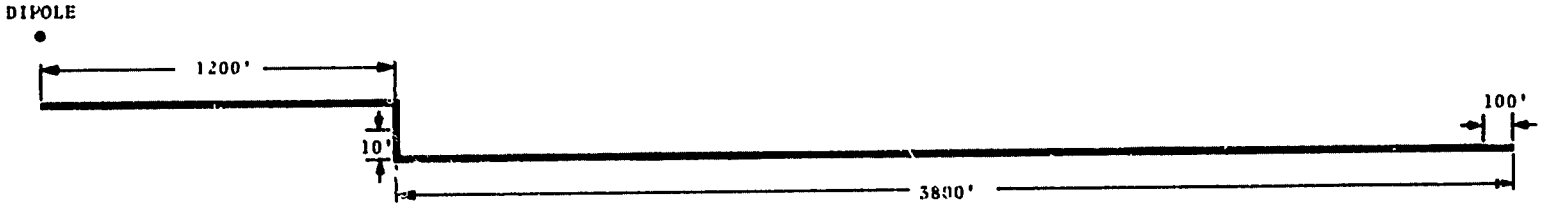


Figure 4. 20-Foot Dropoff

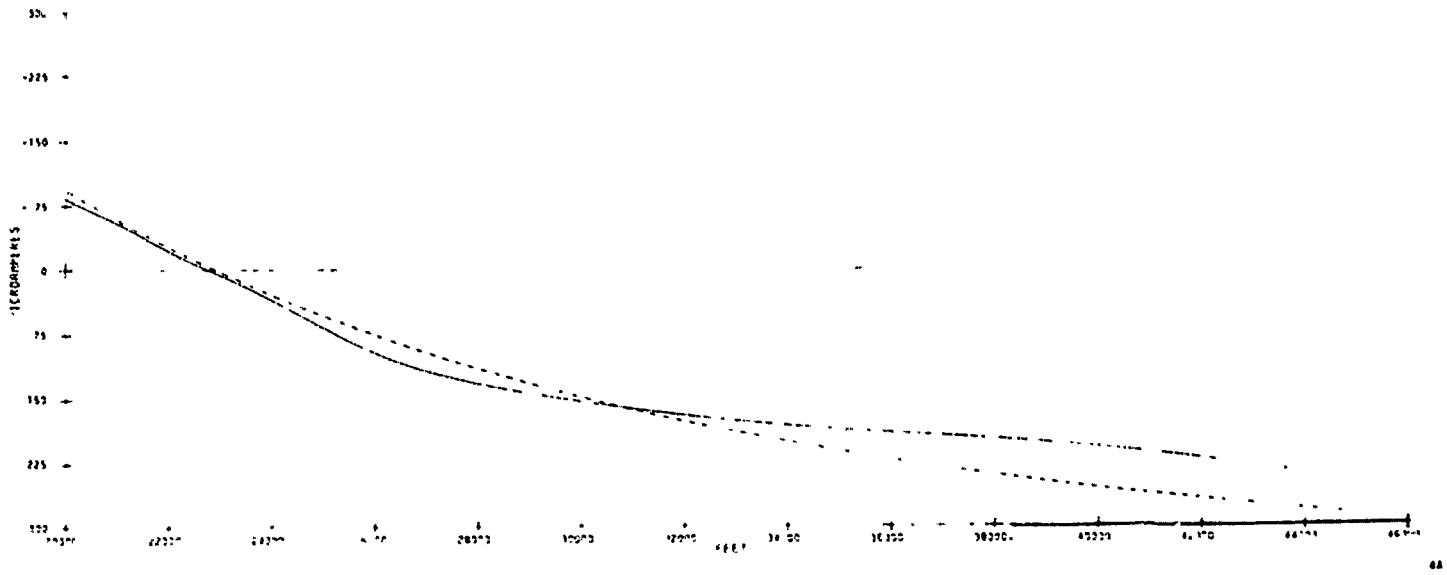


Figure 4A. Null Reference Array, Level Run Flight, 20-Foot Dropoff

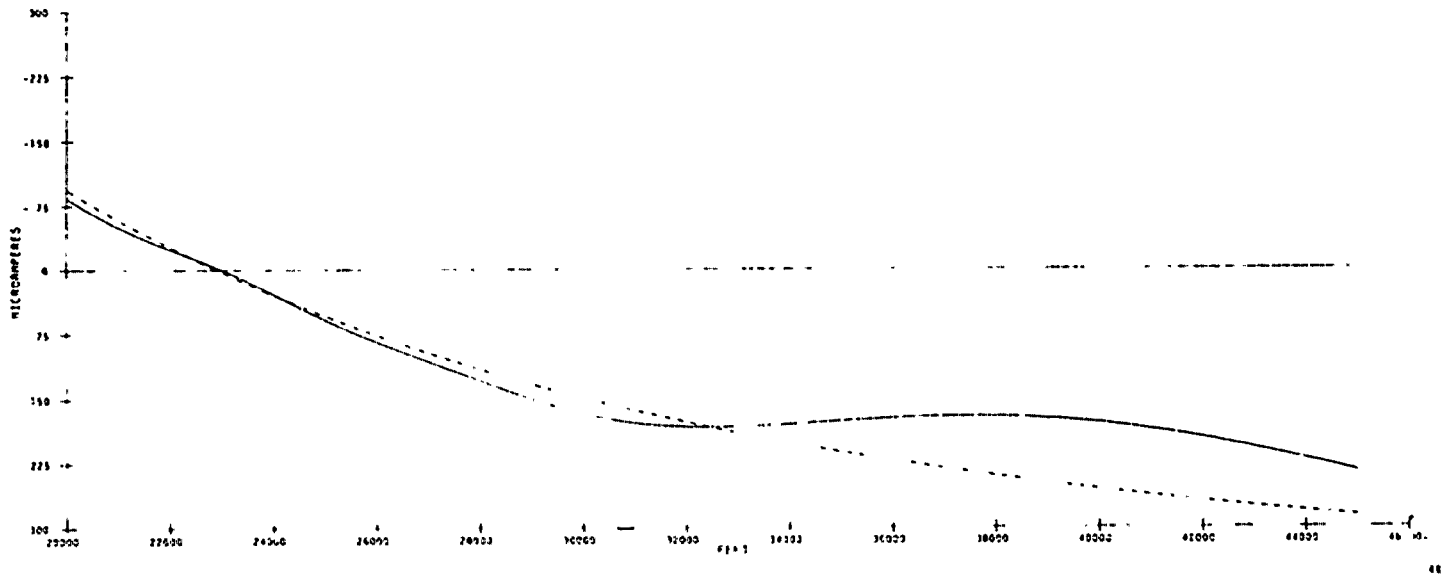


Figure 4B. Sideband Reference Array, Level Run Flight, 20-Foot Dropoff

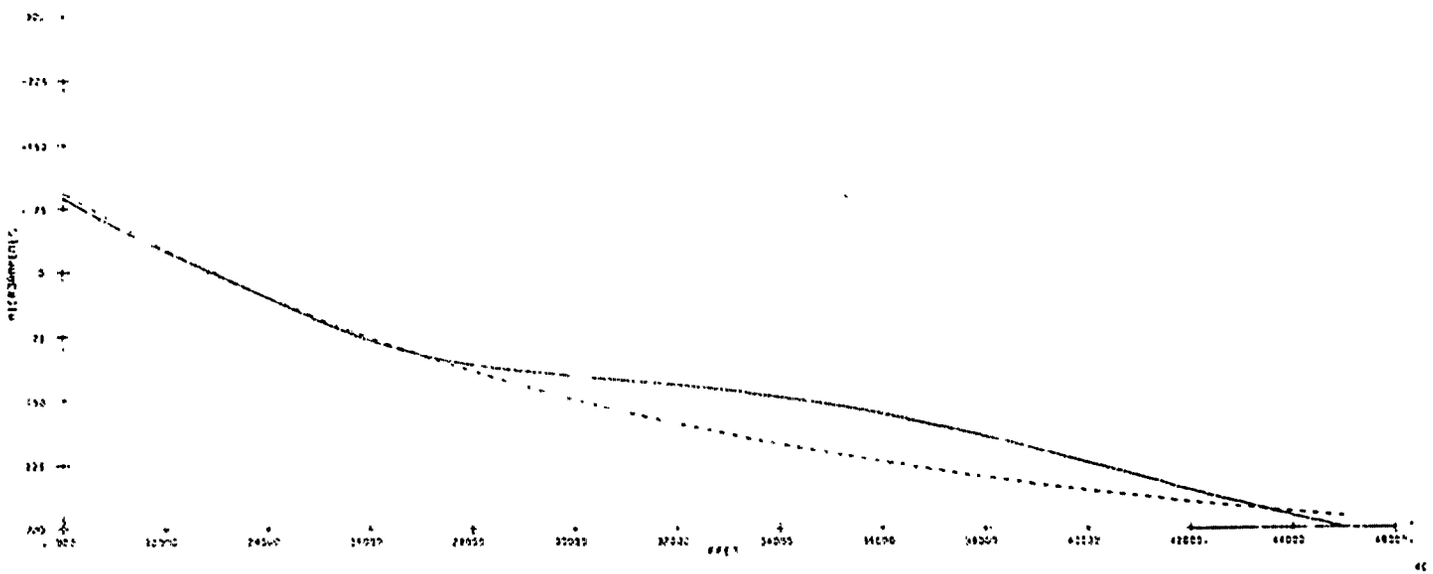


Figure 4C. Capture Effect Array, Level Run Flight, 20-Foot Dropoff

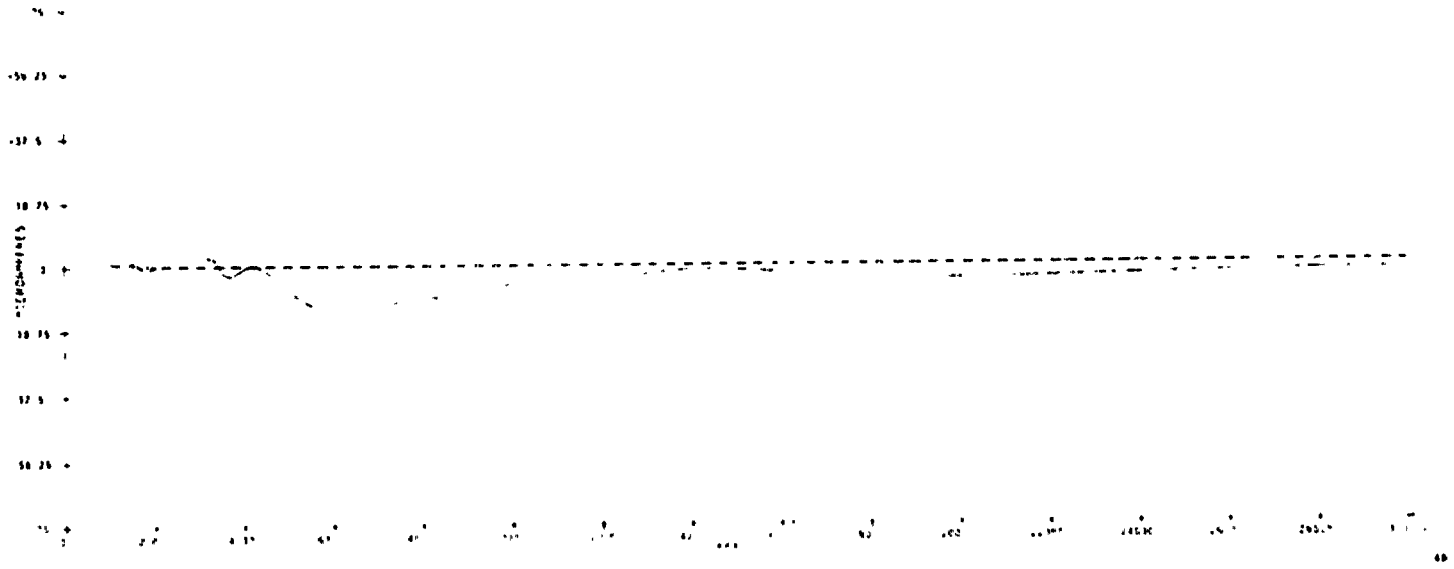


Figure 4D. Null Reference Array, Flyability Run, 20-Foot Dropoff

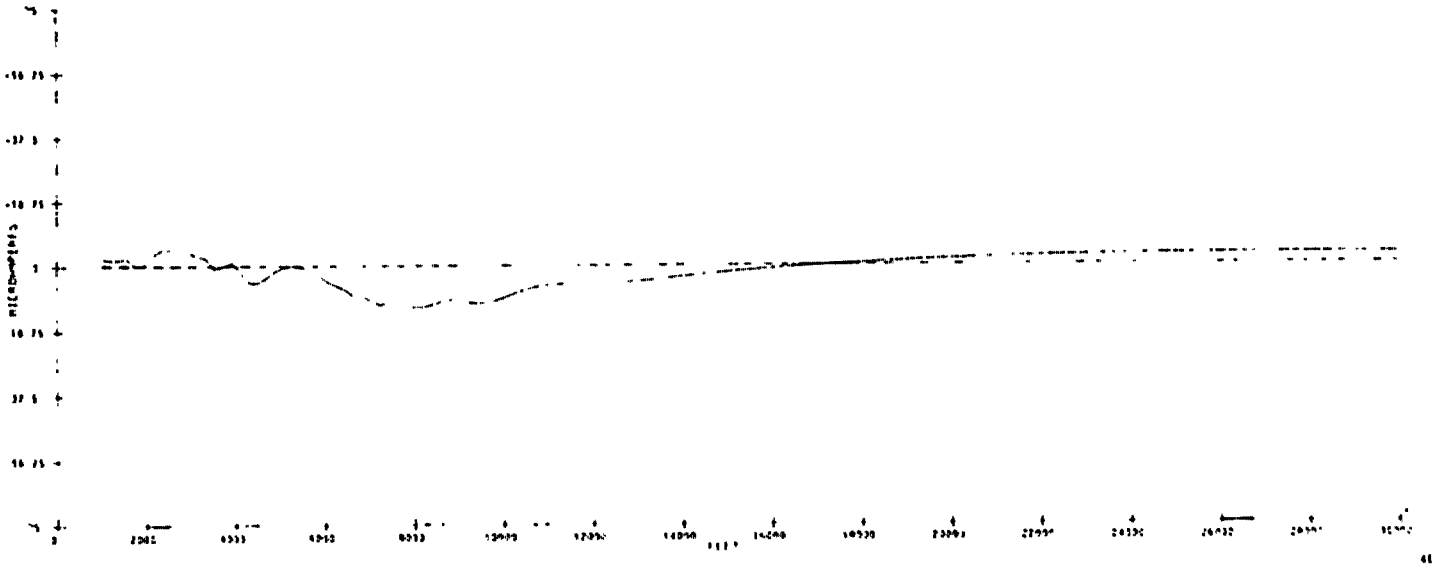


Figure 4E. Sideband Reference Array, Flyability Run, 20-Foot Dropoff

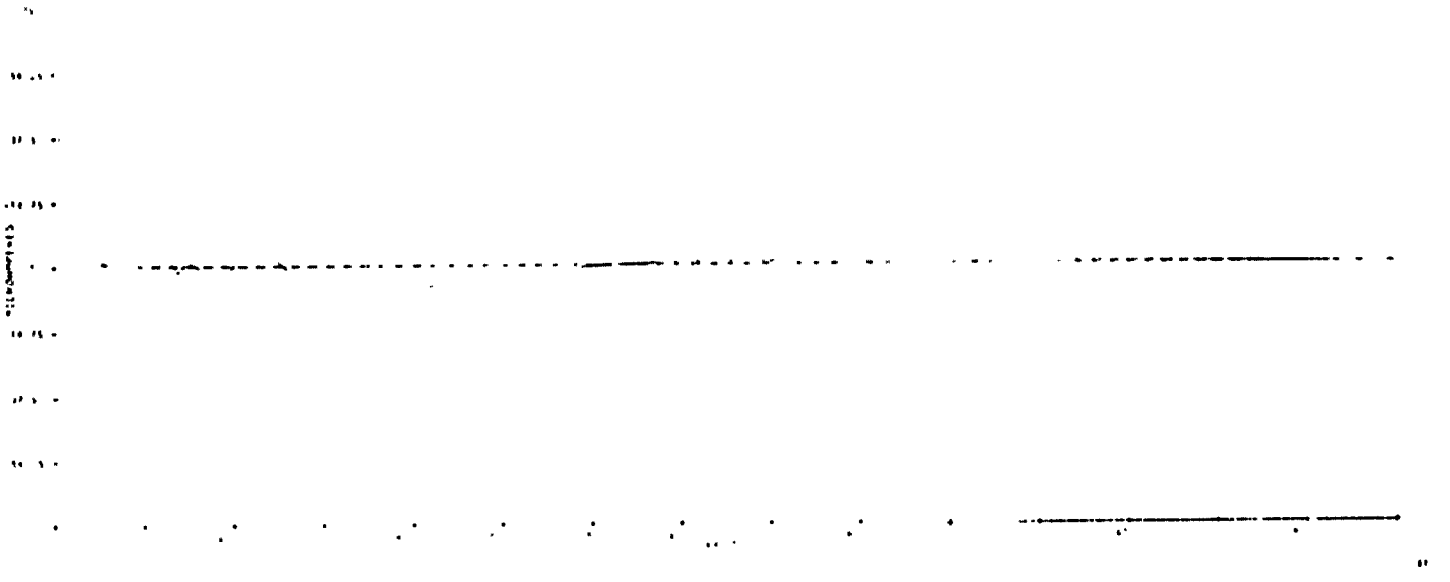


Figure 4F. Capture Effect Array, Feasibility Run, 20-Foot Dropoff

The horizontal flight curve is shifted relative to the ideal curve yielding, over much of the course, stronger fly up signals, weaker fly down signals, and a zero crossing slightly closer to touchdown (an elevated glide path) than are predicted by image theory assuming a flat infinite ground plane.

The nominal flyability run (Fig. 4D) shows a consistent fly up indication over most of the course ranging between 6 and 13 microamperes except between the middle marker and threshold where a fly down signal of -6 microamperes occurs.

The sideband reference data are depicted in Figures 4B and 4E. Note in Figure 4B that the sideband reference zero crossing point is unaffected by the presence of the dropoff. Inside the zero crossing point, the predicted CDI is somewhat weaker than is predicted by image theory while beyond the zero crossing point the predicted CDI is somewhat stronger than is predicted by image theory, at least in the relevant course region (CDI < 150 microamperes).

The flyability run (Fig. 4E) exhibits alternate fly down and fly up indications with peak values ranging from -5 to +12 microamperes.

The capture effect results are shown in Figures 4C and 4F. The level run flight exhibits relatively close agreement between the predicted CDI and the ideal image theory predictions except in the region beyond approximately 27,000 feet where the predicted fly up indication is considerably weaker than is predicted by image theory.

The nominal flyability run exhibits excursions ranging from -4 to 7 microamperes. All these deviations from ideal performance result from reflections from the lower plateau which tend to disrupt the nominal space modulation pattern.

3.4.1 Adjusted Antenna Element Heights

A 3° glide path angle, obtained as the arithmetic mean over the distance between the middle marker and four miles out, was next flown. The 3° glide path angle was obtained by re-positioning

the antenna element heights as shown in Table 2.

TABLE 2.

	Original Positions (feet)			New Positions (feet)		
	Lowest	Middle	Highest	Lowest	Middle	Highest
Null Reference	14.33		28.66	14.45		28.89
S.B. Reference	7.17		21.5	7.21		21.62
Capture Effect	14.33	28.66	42.99	14.35	28.72	43.08

The level flight results with this new antenna element positioning are shown in Figures 4G, 4H, and 4I. These new results are only slightly different from the original as might be expected with only a slight change in the antenna element heights.

The flyability run results are shown in Figures 4J, 4K, and 4L. The null reference flyability run, Figure 4J exhibits a mostly fly up indication with a peak value of 8 microamperes. Near the middle marker region there is a fly down indication with a peak value of -11 microamperes.

The sideband reference and capture effect antennas (Figures 4K and 4L, respectively) behave similarly, with peak values ranging from -9 to +8 microamperes for the sideband antenna and ranging from -6 to +6 microamperes for the capture effect antenna.

3.5 DROPOFF AND UPGRADE

The next terrain configuration to be discussed is depicted in Figure 5. The terrain consists of 1200 feet of flat ground ending in a 40 foot drop followed by an upgrade rising 58 feet in 1900 feet and finally terminating with 1900 feet of flat ground. This terrain configuration as well as the others previously discussed was suggested to us for study by the FAA. The null reference data are shown in Figures 5A and 5D. The level run flight results (Fig. 5A) show considerable deviation from the ideal. The zero crossing point is shifted by nearly 2000 feet toward touchdown (equivalent to an elevation of the glide path to 3.19°). Course

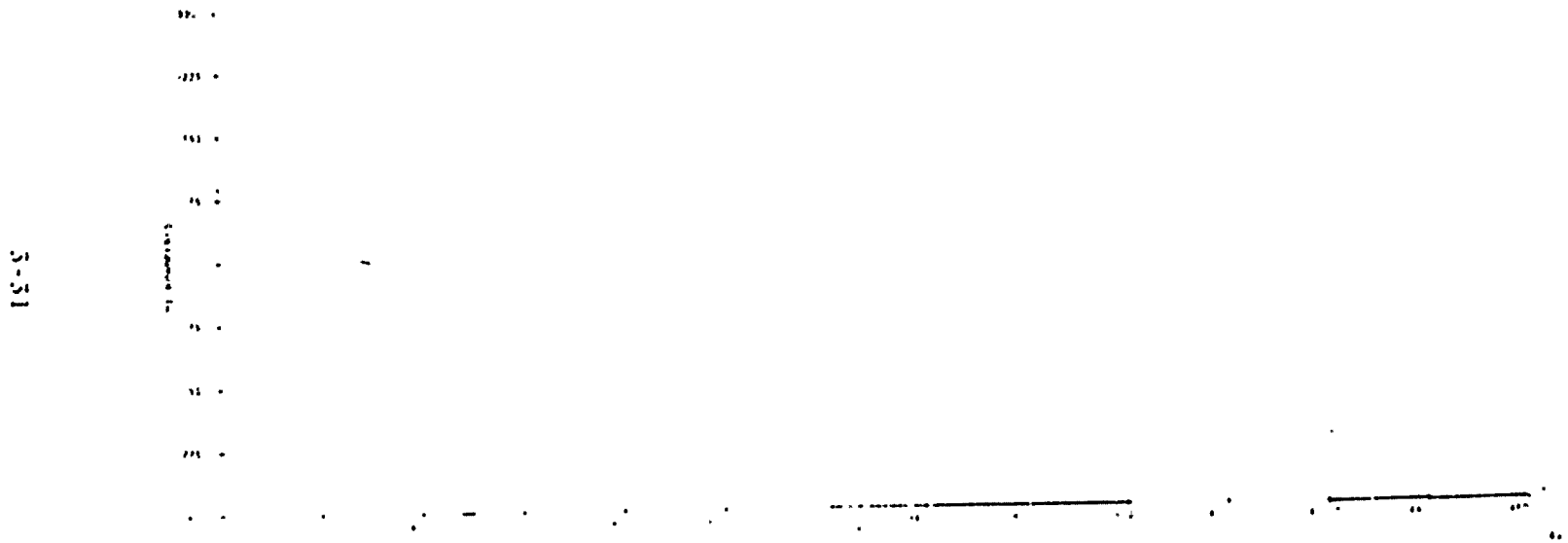


Figure 46. Adjusted Null Reference Array, Level Run Flight, 20-Foot Dropoff

Figure 48. Adjusted Sideband Reference Array, Level Run Flight, 20-Foot Dropoff

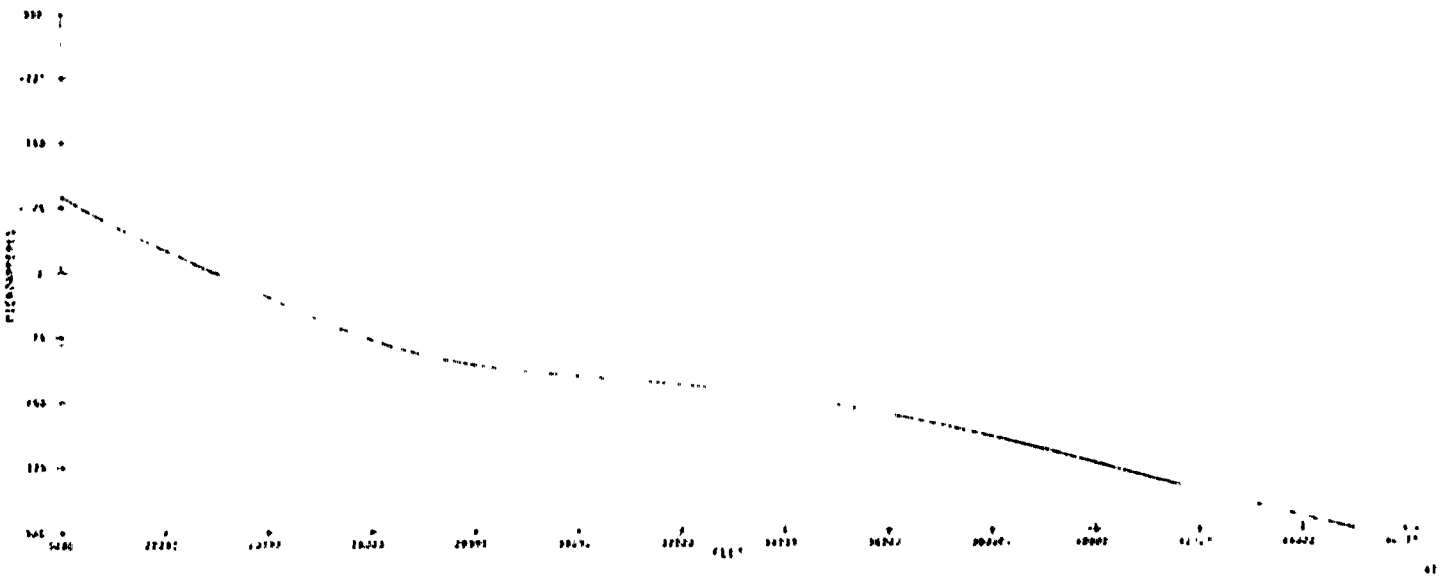


Figure 41. Adjusted Capture Effect Array, Level Run Flight, 20-Foot Dropoff

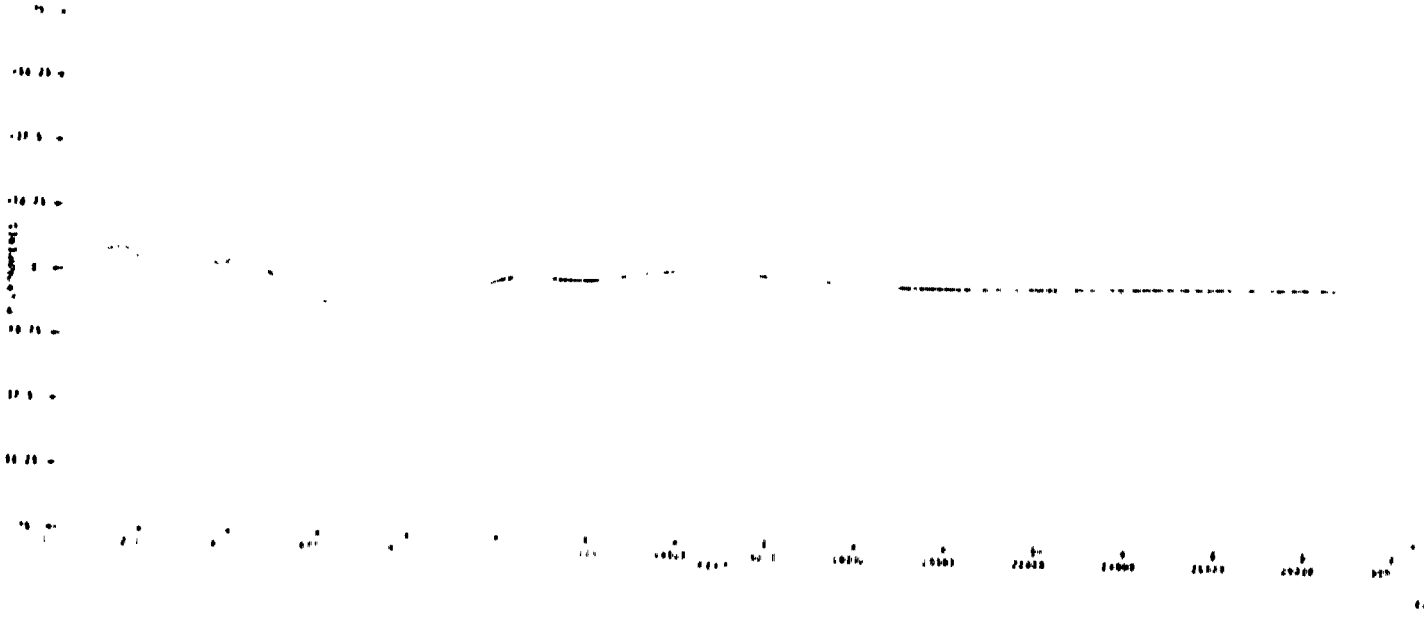


Figure 4J. Adjusted Null Reference Array, Flyability Run, 20-Foot Dropoff

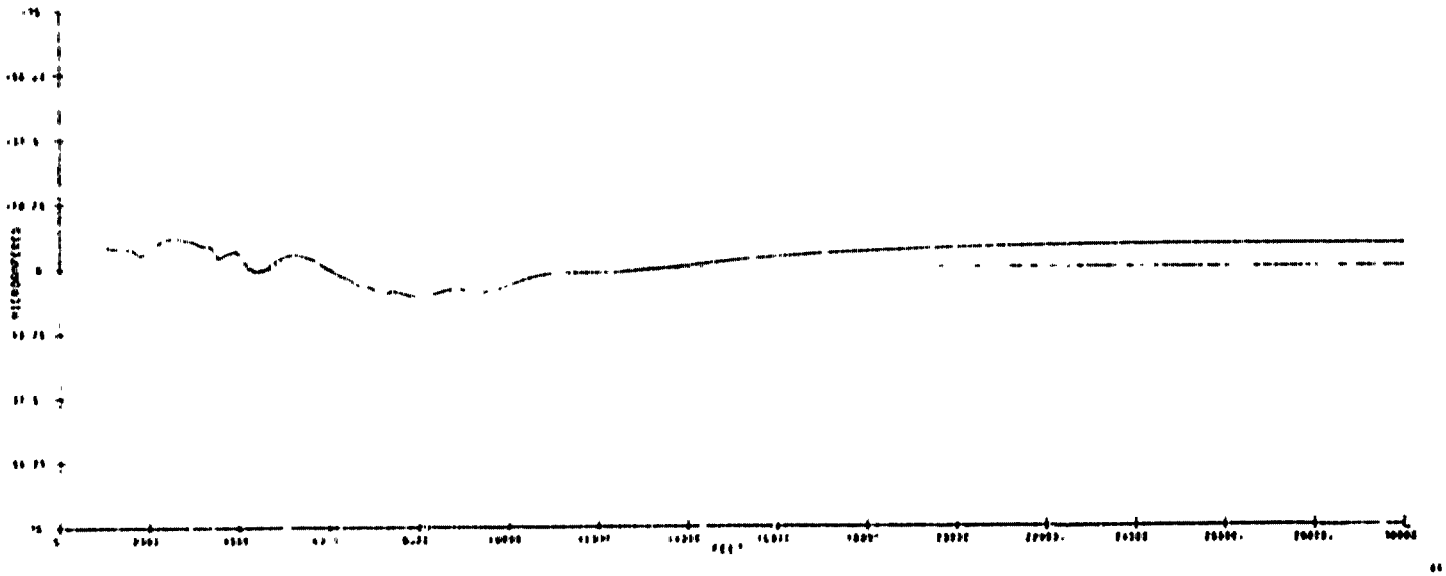


Figure 4K. Adjusted Sideband Reference Array, Flyability Run, 20-Foot Dropoff

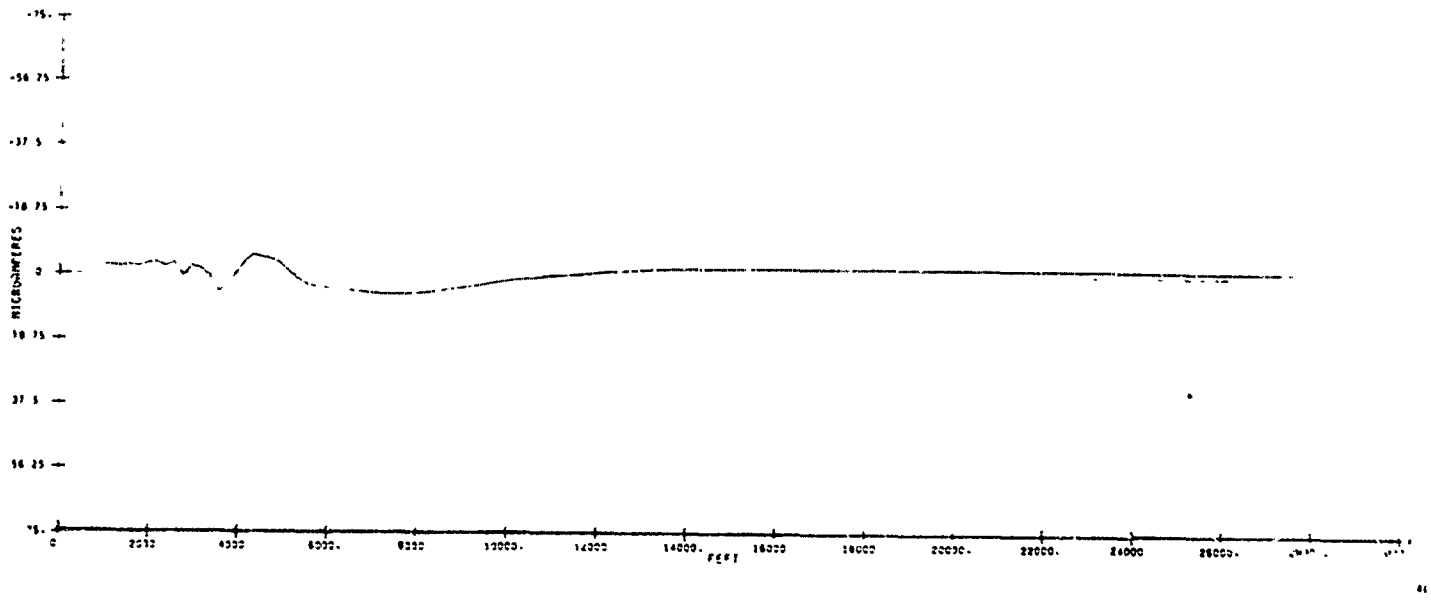


Figure 41. Adjusted Capture Effect Array, Flyability Run, 20-Foot Dropoff

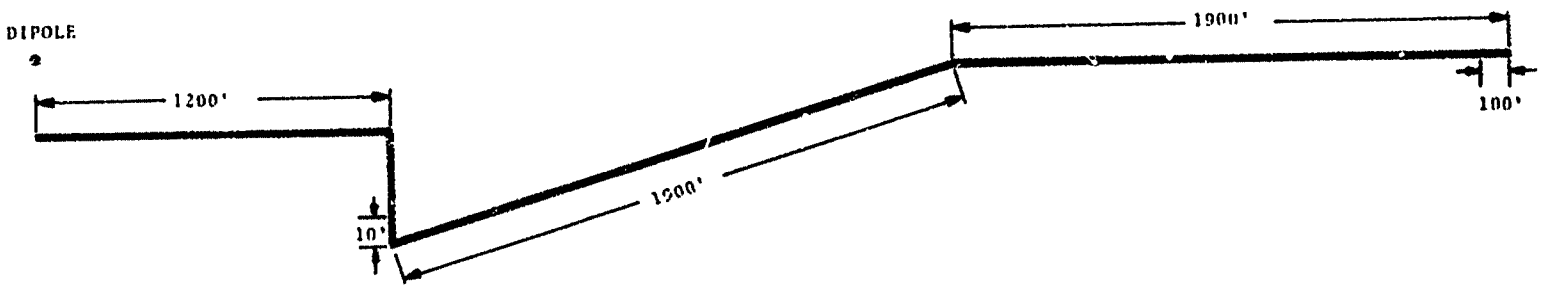


Figure 5. Dropoff and Upgrade

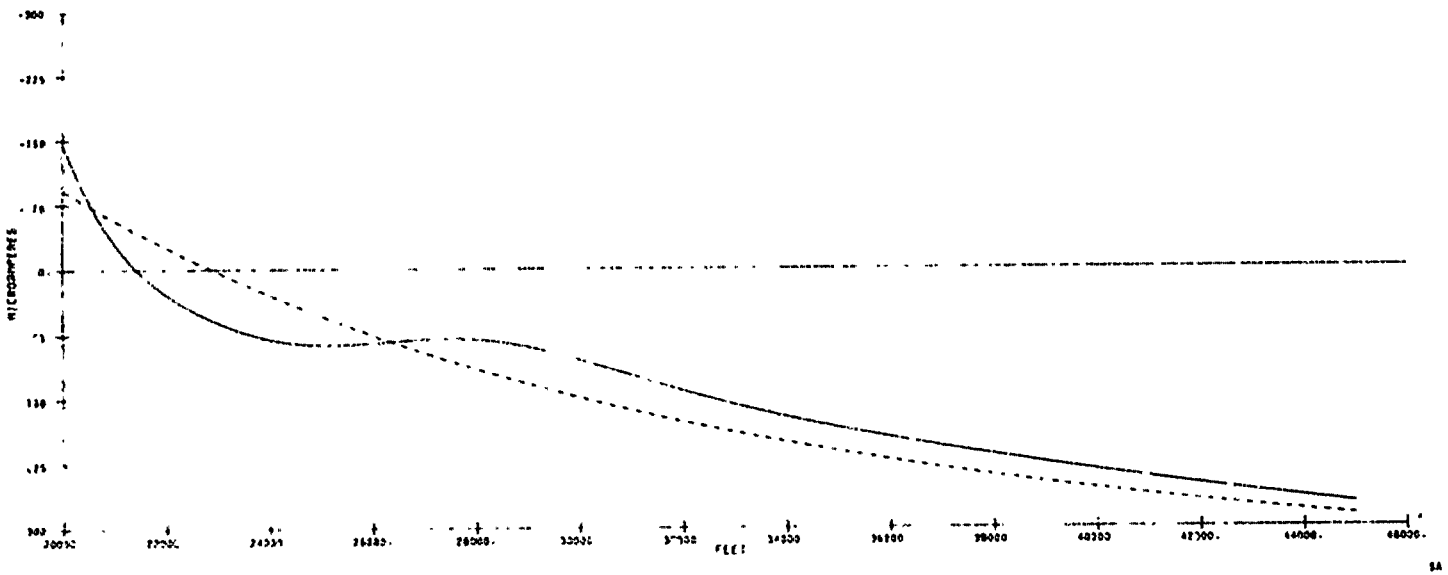


Figure 5A. Null Reference Array, Level Run Flight, Dropoff and Upgrade

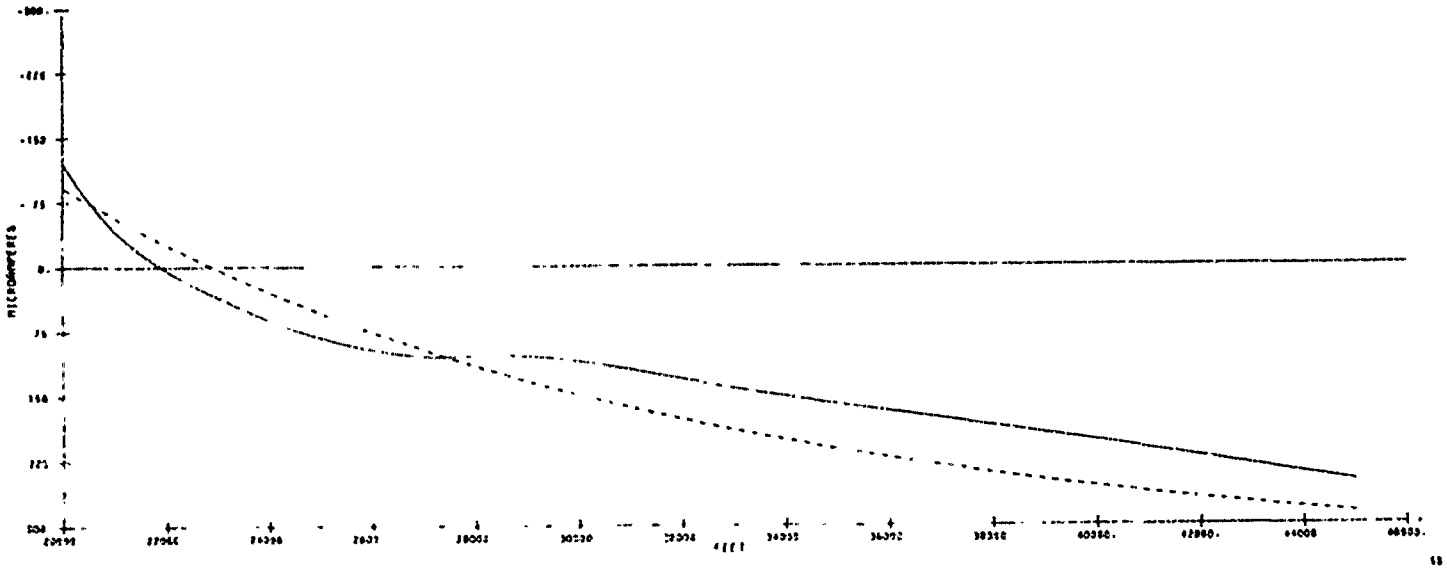


Figure 5B. Sideband Reference Array, Level Run Flight, Dropoff and Upgrade

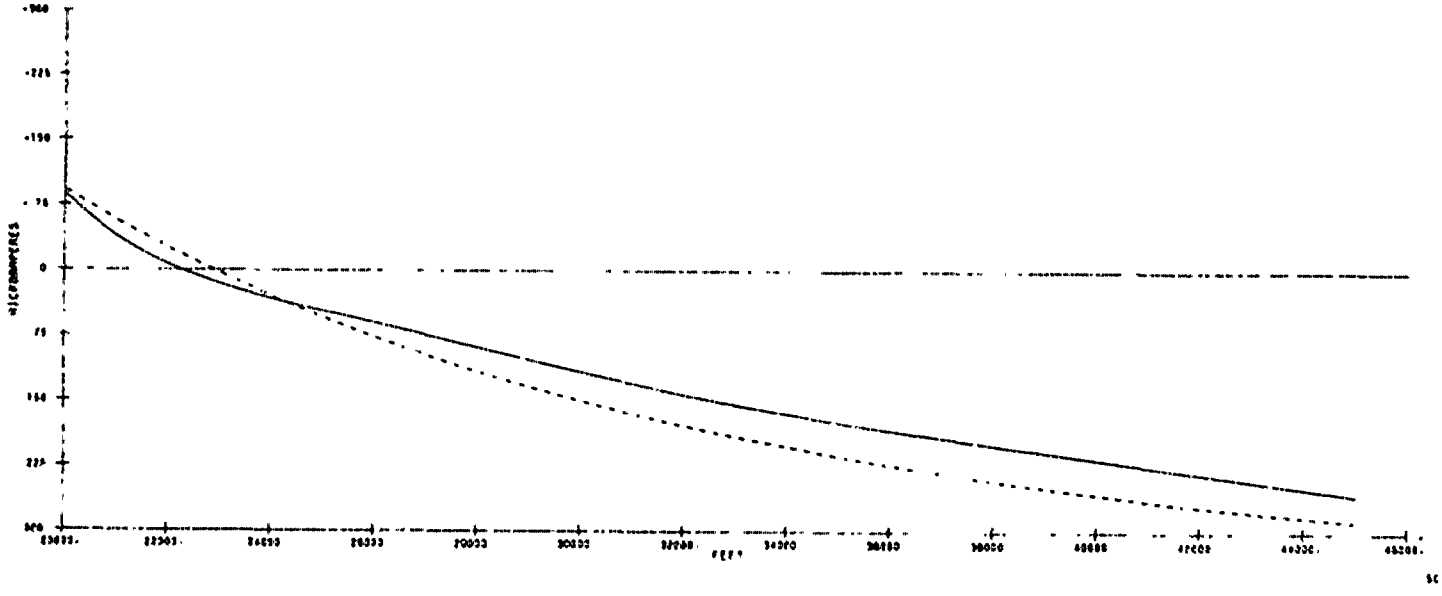


Figure 5C. Capture Effect Array, Level Run Flight, Dropoff and Upgrade

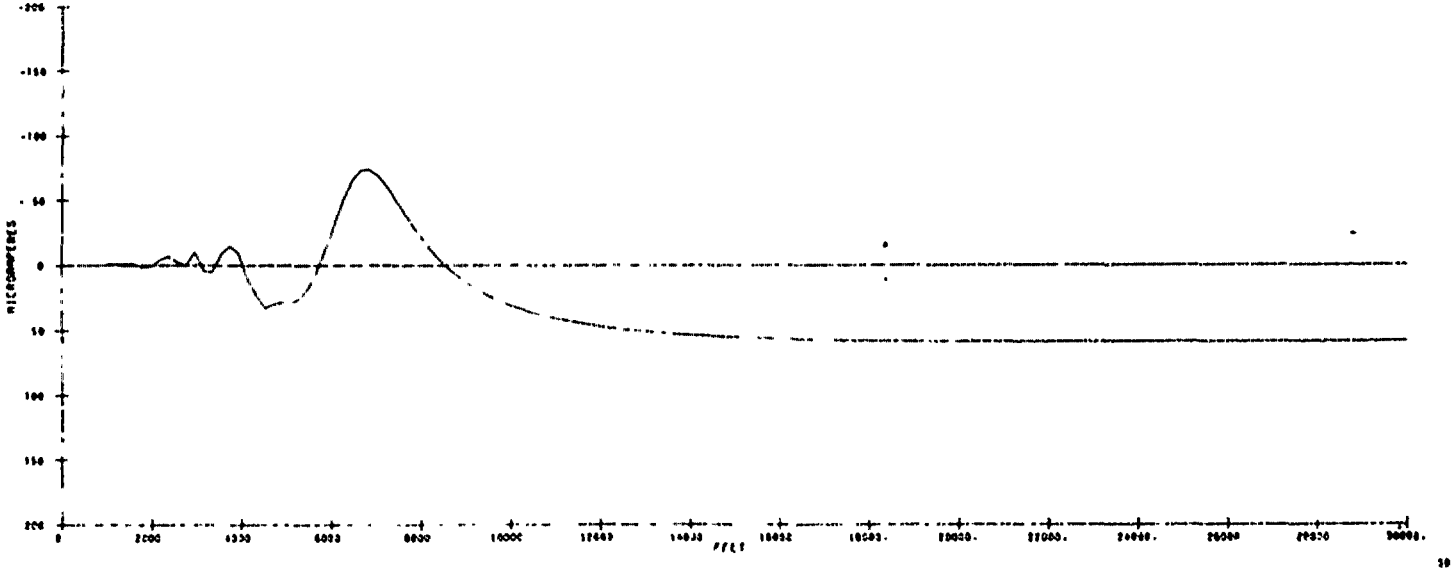


Figure 5D. Null Reference Array, Flyability Run, Dropoff and Upgrade

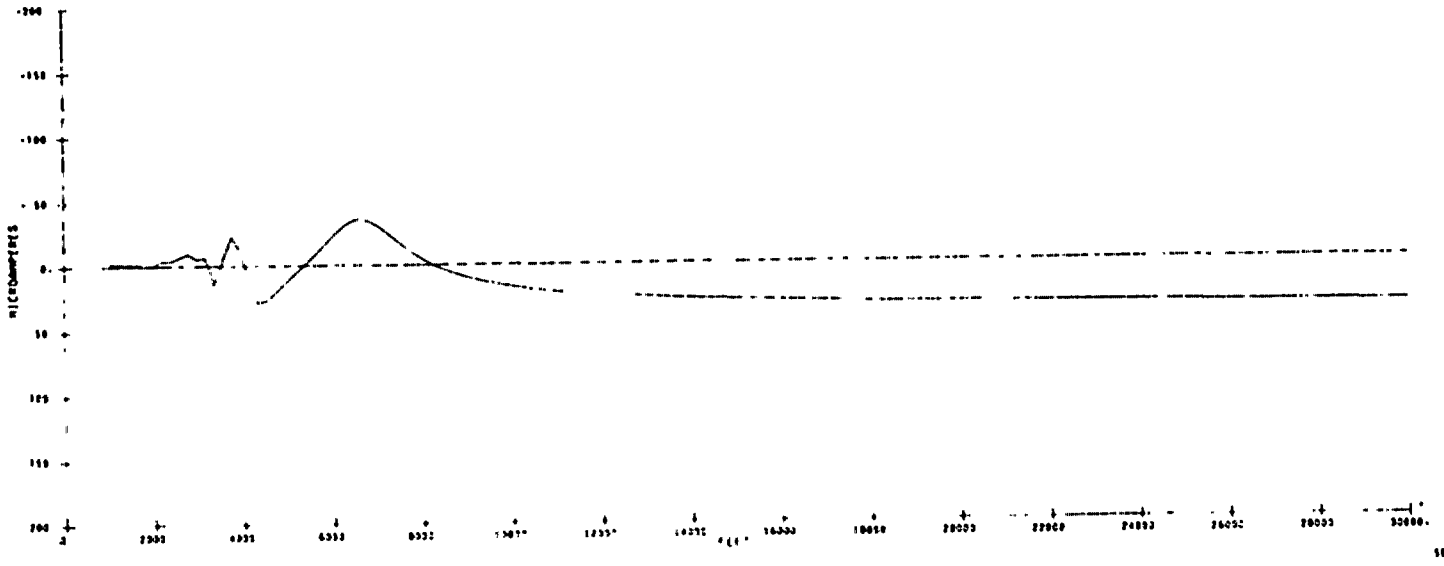


Figure 5E. Sideband Reference Array, Flyability Run, Dropoff and Upgrade

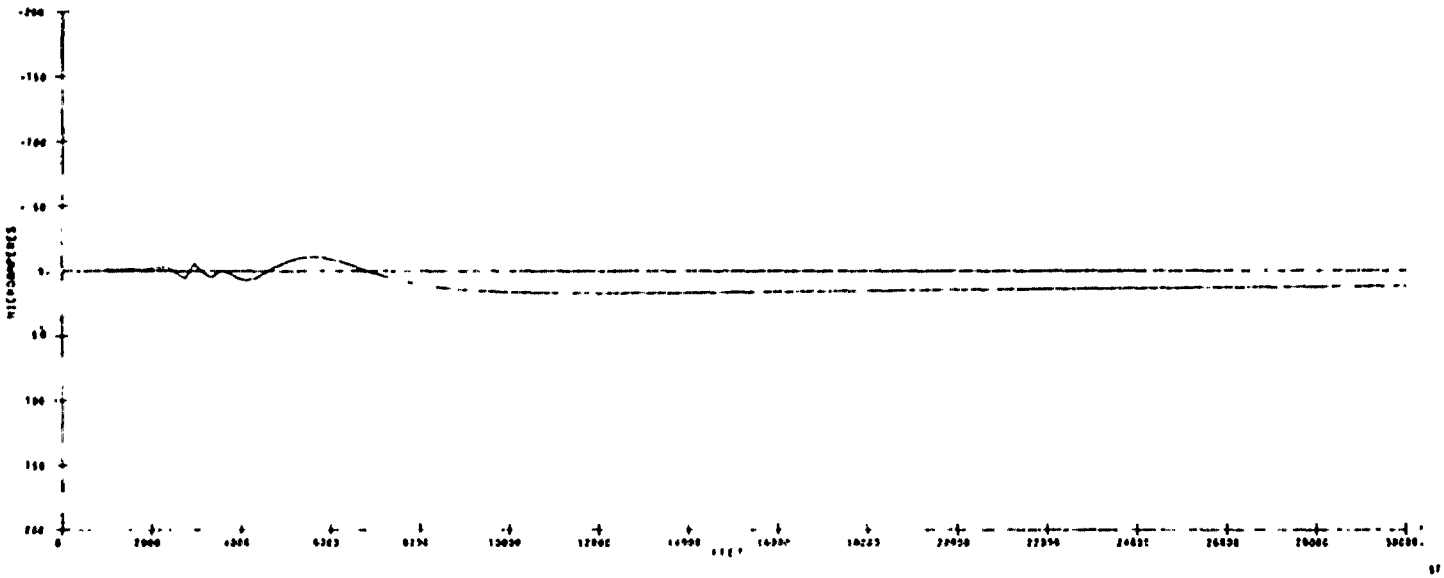


Figure 5F. Capture Effect Array, Flyability Run, Dropoff and Upgrade

linearity is greatly distorted. Note that the curve is almost level from 25,000 feet out to 29,000 feet.

The nominal flyability results (Fig. 5D) reveal a strong fly up indication of about 60 microamperes over much of the course and an even stronger fly down signal at about 7000 feet from touchdown of about -70 microamperes.

The sideband reference results (Figs. 5B and 5E) are qualitatively very similar to the null reference results but, quantitatively, the distortions are not as severe. It will be noted in Figure 5E that the excursions are about ±35 microamperes in magnitude as compared with 60 and -70 microamperes in the case of the null reference array.

The capture effect results (Figs. 5C and 5F) show the least distortion. In Figure 5C, it can be seen that the zero crossing point undergoes a relatively modest displacement, the nominal glide path results (Fig. 5E) exhibits excursions ranging from -11 to 17 microamperes, a decided improvement over the null reference and sideband reference arrays.

3.5.1 Adjusted Antenna Element Heights

In an attempt to improve the flyability of this course, the antenna element heights were adjusted to give a mean 3° glide path angle over the distance between the middle marker and four miles out. The new antenna element heights are shown in Table 3

TABLE 3.

	Original Positions (feet)			New Positions (feet)		
	Lowest	Middle	Highest	Lowest	Middle	Highest
Null Reference	14.33		28.66	15.02		30.04
S.B. Reference	7.17		21.5	7.35		22.04
Capture Effect	14.33	28.66	42.99	14.59	29.18	43.77

The level flight results with this new positioning are shown in Figures 5G, 5H, and 5I. The flyability results are shown in Figures 5J, 5K, and 5L.

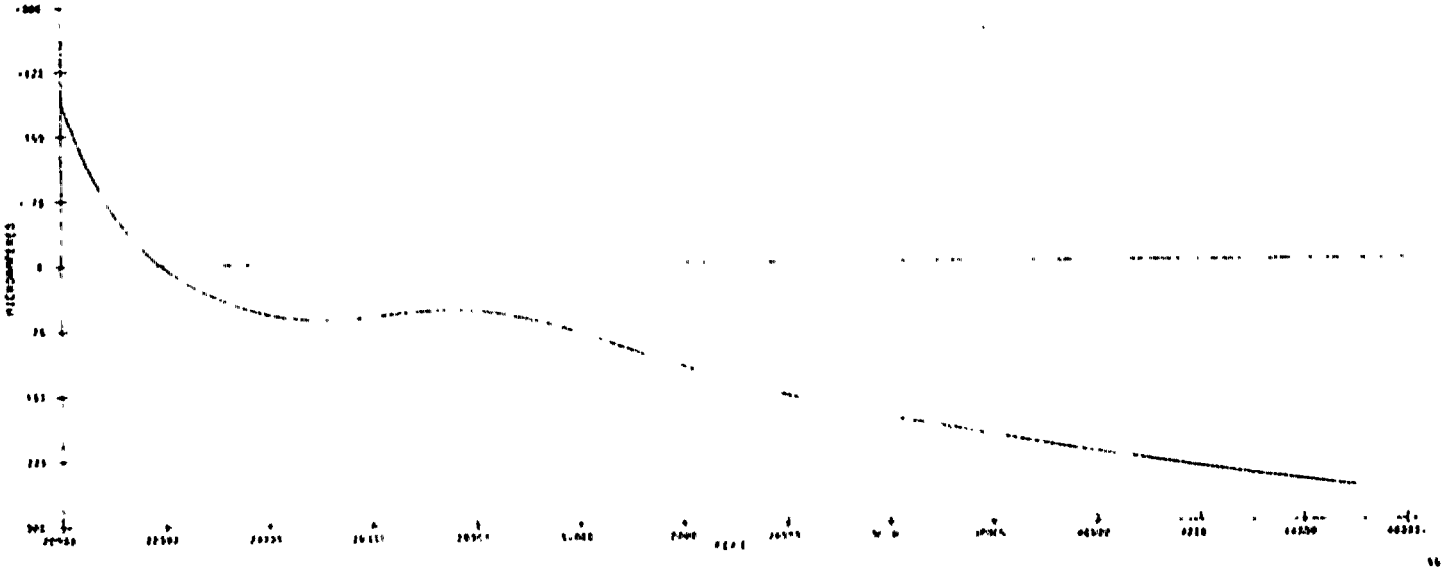


Figure 56. Adjusted Null Reference Array, Level Run Flight, Dropoff and Upgrade

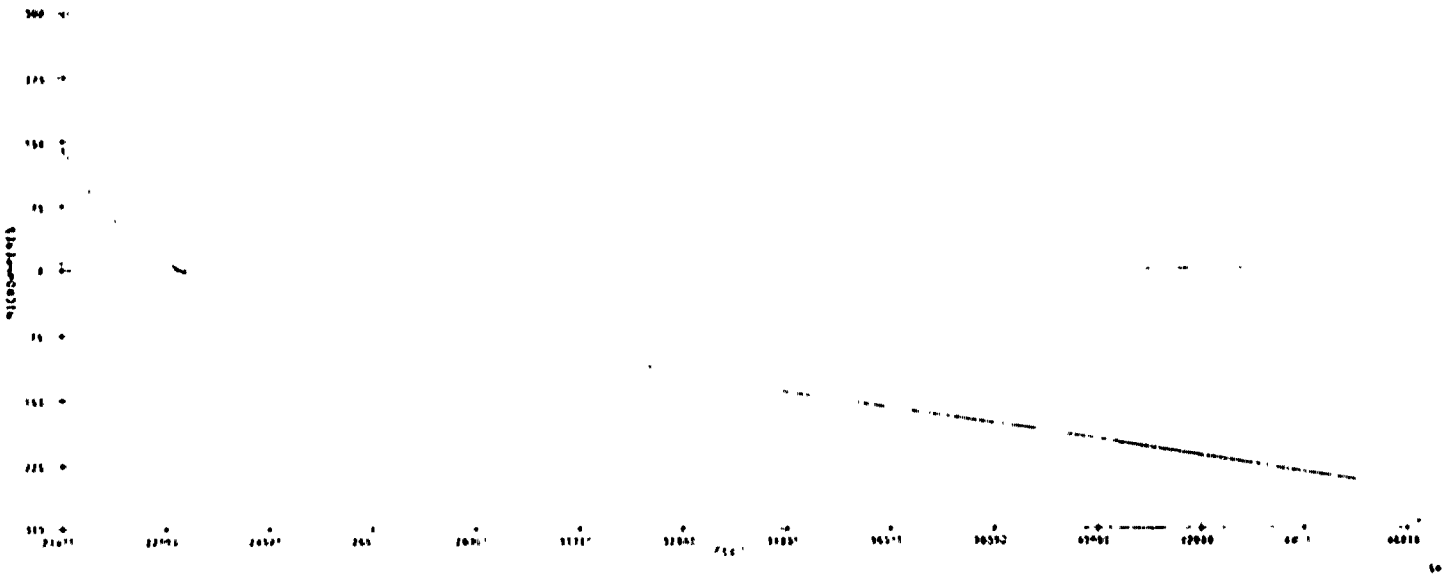


Figure 5H. Adjusted Sideband Reference Array, Level Run Flight, Dropoff and Upgrade

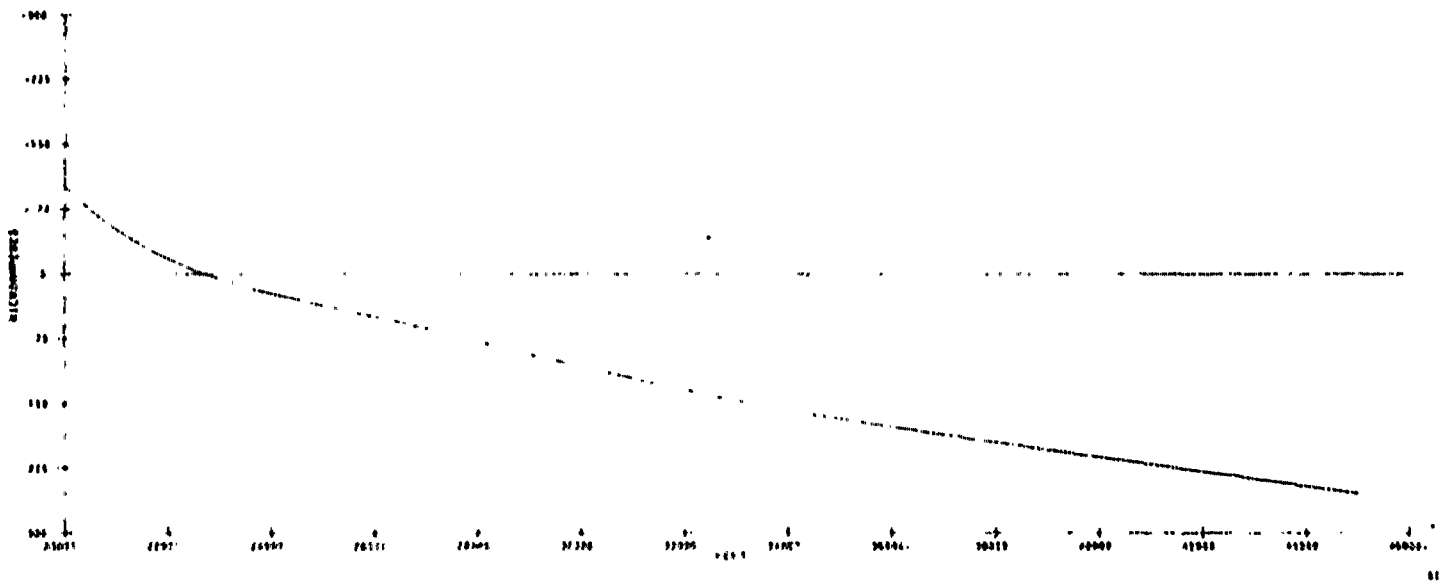


Figure 51. Adjusted Capture Effect Array, Level Run Flight, Dropoff and Upgrade

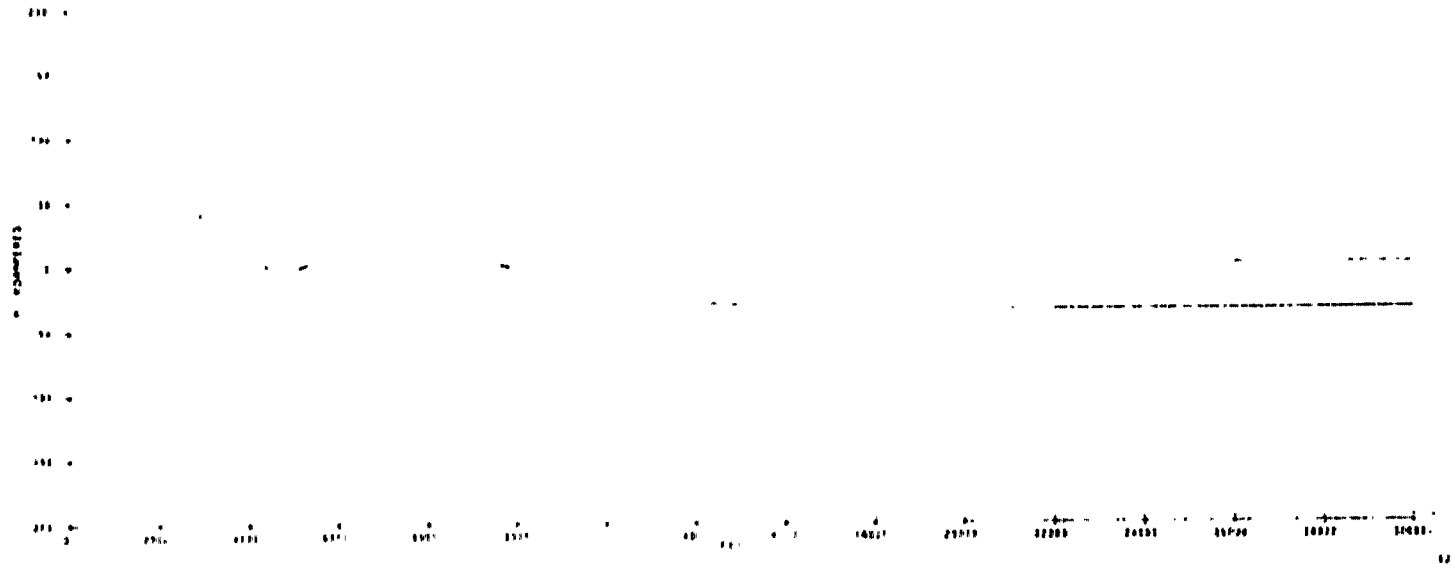


Figure 51. Adjusted Null Reference Array, Flyability Run, Dropoff and Upgrade

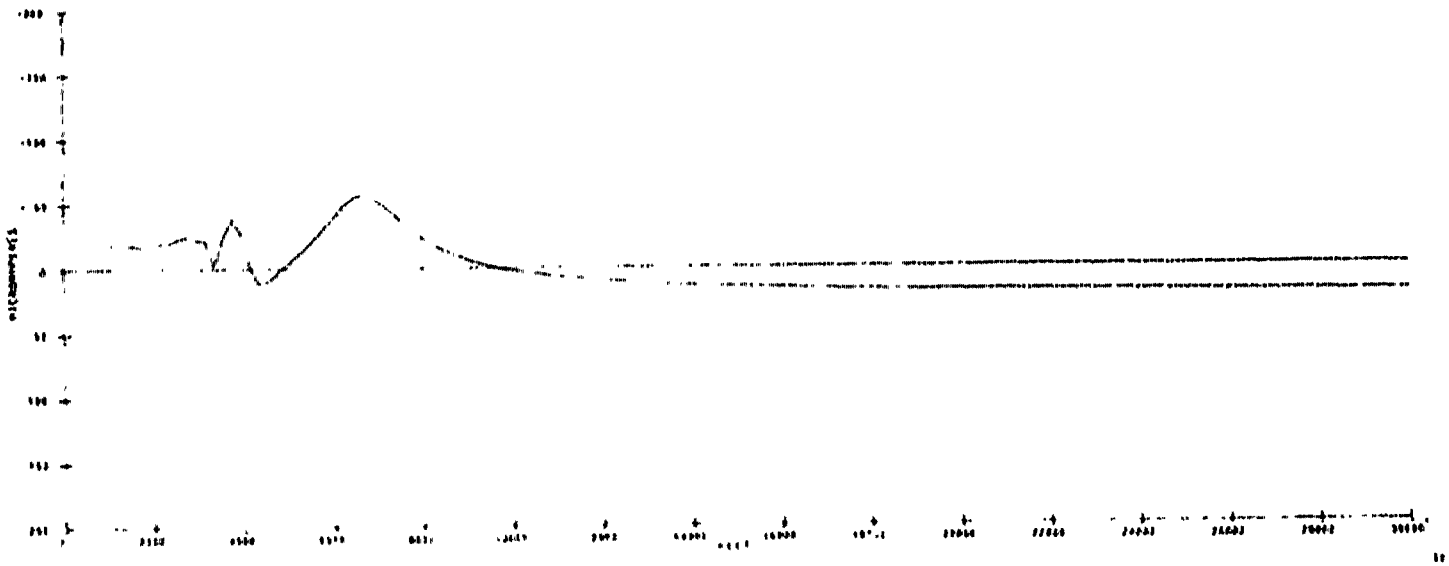


Figure 5K. Adjusted Sideband Reference Array, Flyability Run, Dropoff and Upgrade

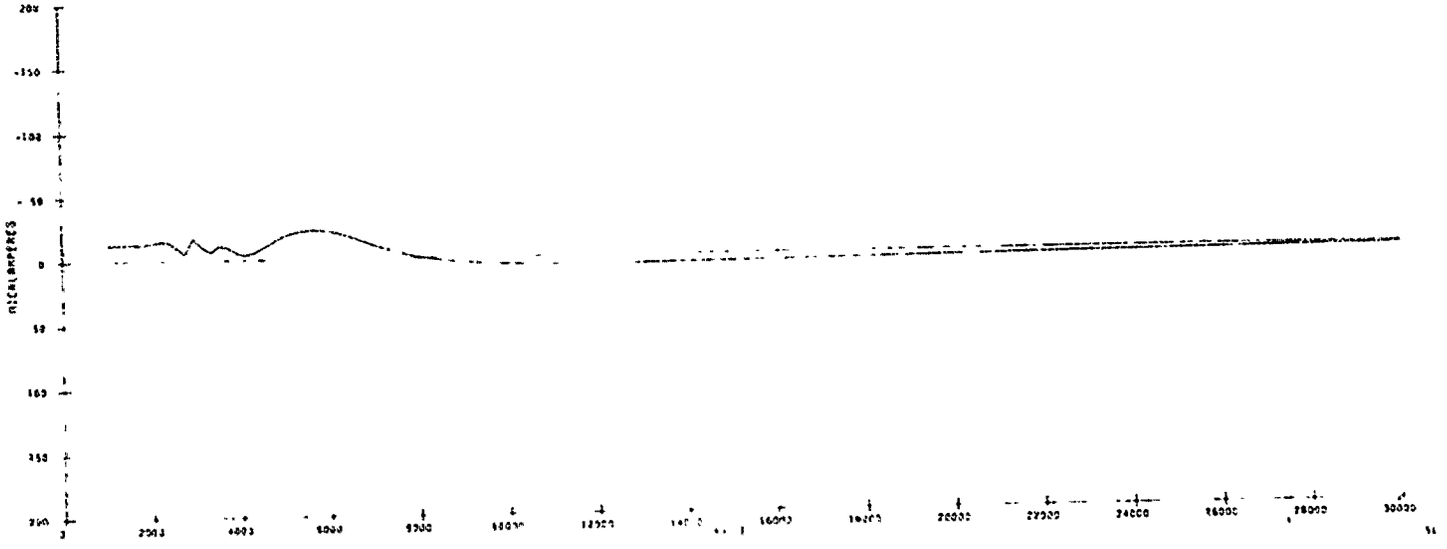


Figure 5L. Adjusted Capture Effect Array, Flyability Run, Dropoff and Upgrade

Re-positioning of the antenna element heights for this type of terrain to obtain a mean 3° glide path angle does not improve the course though the cross overs (Figures 5G, 5H, and 5I) do occur somewhat closer to the required 3° glide angle. As can be seen on comparing Figure 5J, 5K, and 5L with the uncorrected values shown in Figures 5D, 5E, and 5F, the flyability of the course has not improved by this re-positioning. The peak-to-peak values are now -115 to 21 microamperes for the null reference antenna; -57 to 21 microamperes for the sideband reference antenna; and -22 to 7 microamperes for the capture effect antenna. While the fly up indications have in all cases been reduced, the fly down indications have all gone up. This is because the re-positioning of the antenna element heights simply shifts the CDI pattern either up or down. This type of correction is very useful when a uniform shift of the CDI pattern occurs, for example, when the terrain has an up or down slope, as was the case depicted in Figure 3. Adjusting the antenna element heights there for a mean 3° glide path angle shifted the whole pattern back toward zero CDI. However, for the terrain depicted in Figure 5, which produced both up and downward CDI shifts (as shown in Figures 5D, 5E, and 5F), the simple translation of the CDI pattern that was produced by adjusting the antenna element heights for a mean 3° glide path angle, cannot yield zero CDI over the whole course. By reducing the fly up indications, the fly down indications, in fact, became stronger.

We do emphasize again, however, that for this terrain the sideband reference antenna produced a much improved course over the null reference, and that the capture effect antenna a much improved course over the sideband reference antenna.

3.6 UPGRADE, DROPOFF AND UPGRADE

The next terrain configuration to be discussed is depicted in Figure 6. The terrain consists of 1000 feet of ground sloping up at 3/4° ending in a 20 foot drop which is then followed by 500 feet of flat ground followed by 3500 feet of ground again sloping up at 3/4°. The results are shown in Figures 6A, 6B, 6C, 6D, 6E, and 6F.

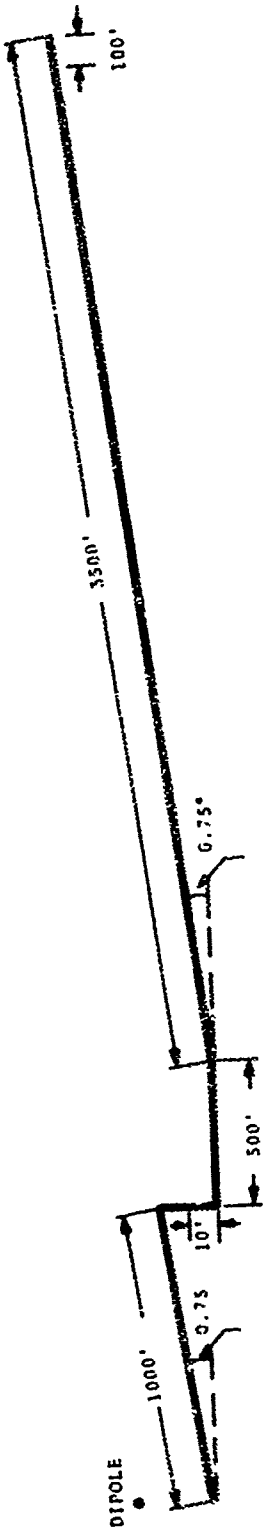


Figure 6. Upgrade, Dropoff and Upgrade

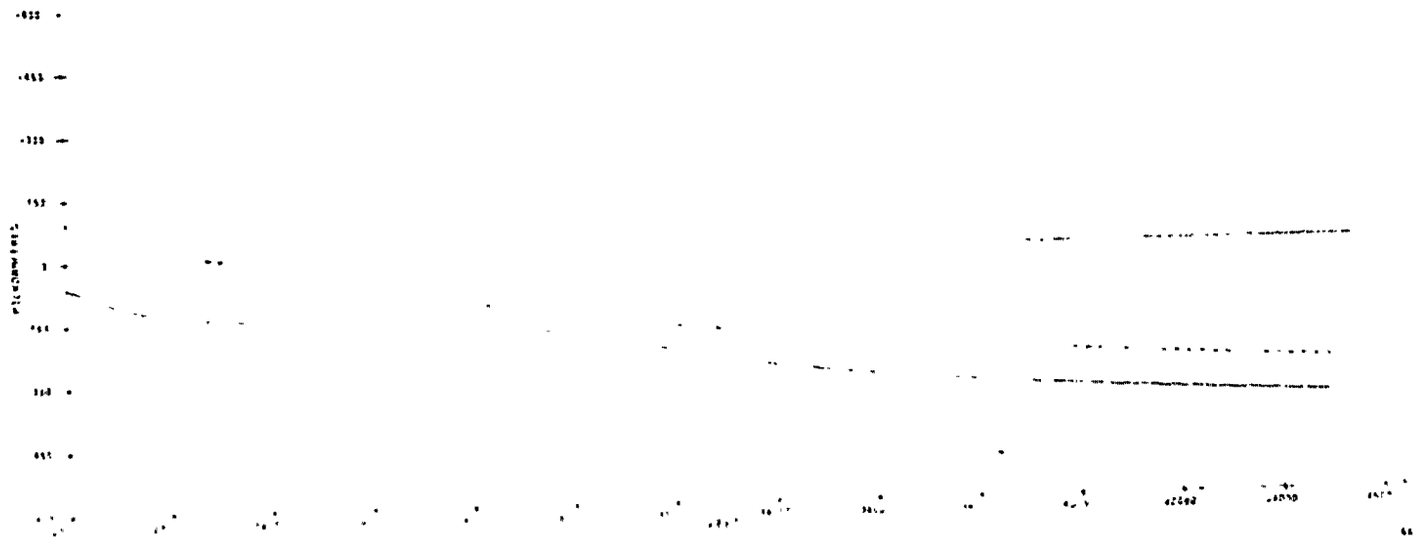


Figure 6A. Null Reference Array, Level Run Flight, Upgrade, Dropoff and Upgrade

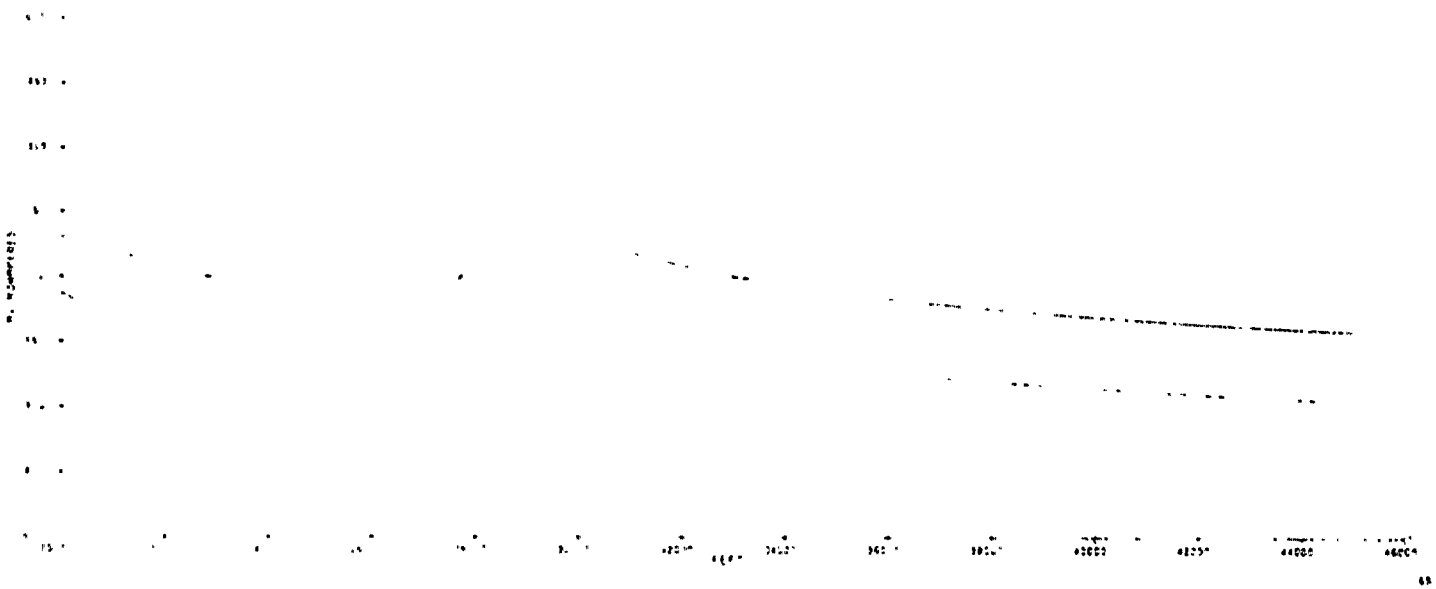


Figure 6B. Sideband Reference Array, Level Run Flight, Upgrade, Dropoff and Upgrade

Figure 6C. Capture Effect Array, Level Run Flight, Upgrade, Dropoff and Upgrade

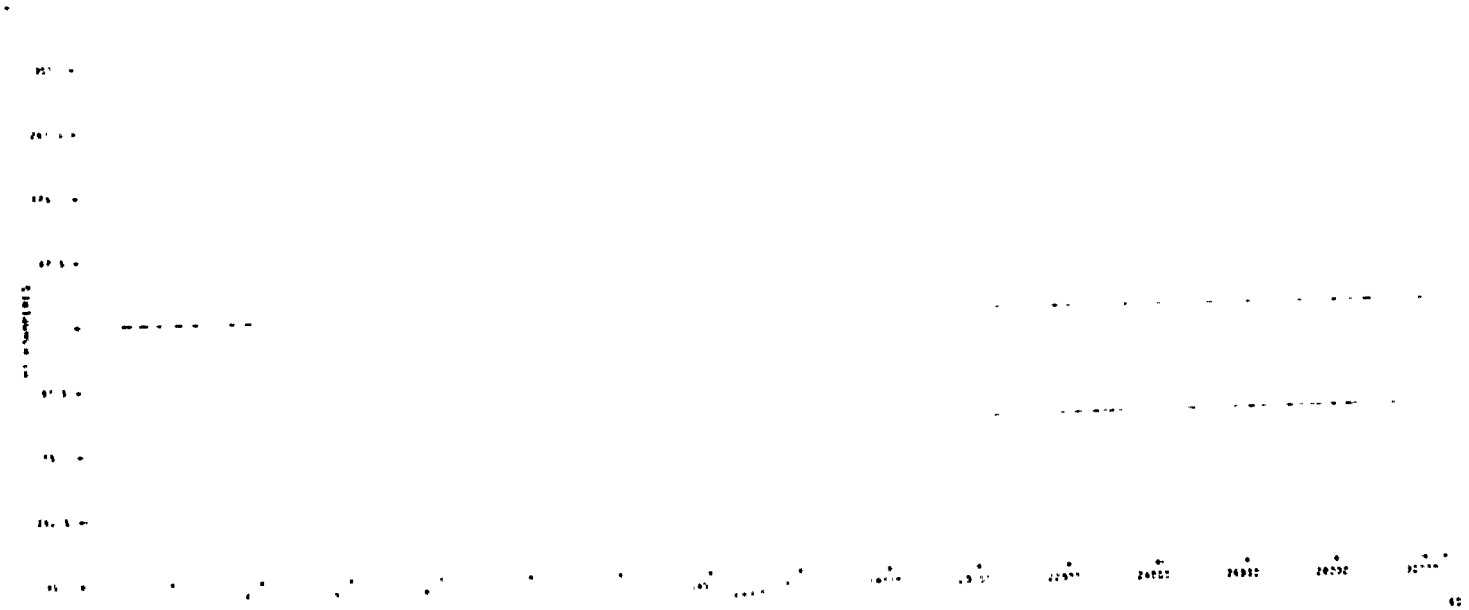


Figure 6D. Null Reference Array, Flyability Run, Upgrade, Dropoff and Upgrade

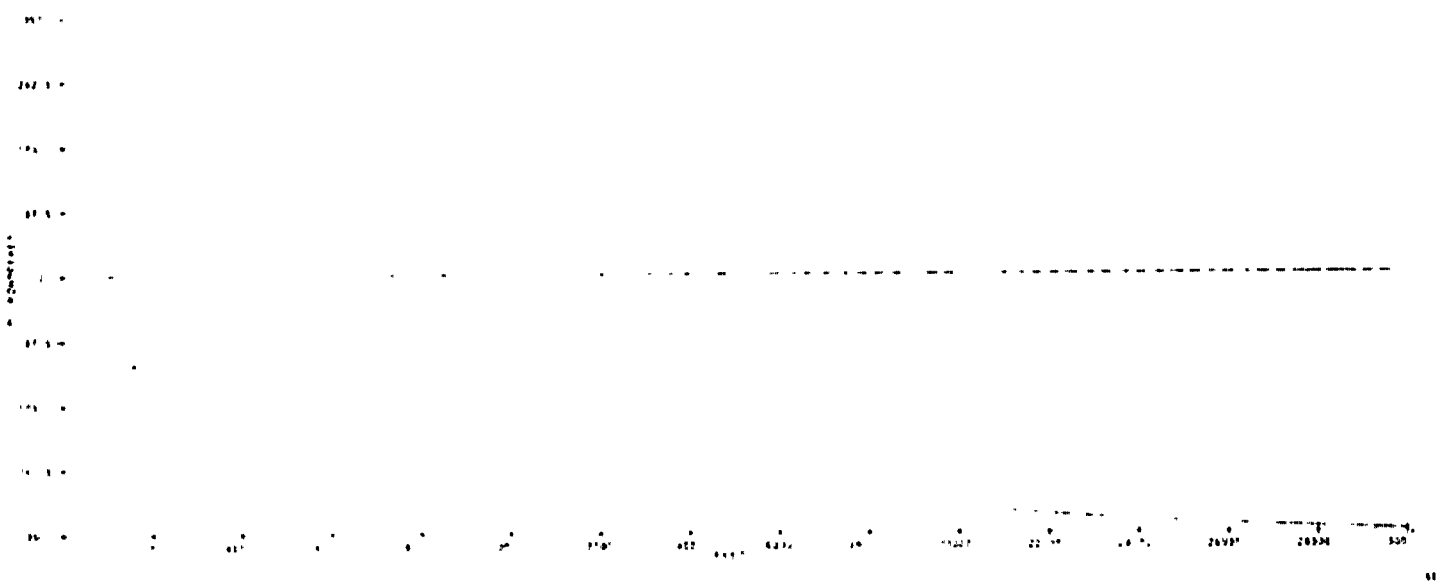


Figure 6E. Sideband Reference Array, Flyability Run, Upgrade, Dropoff and Upgrade

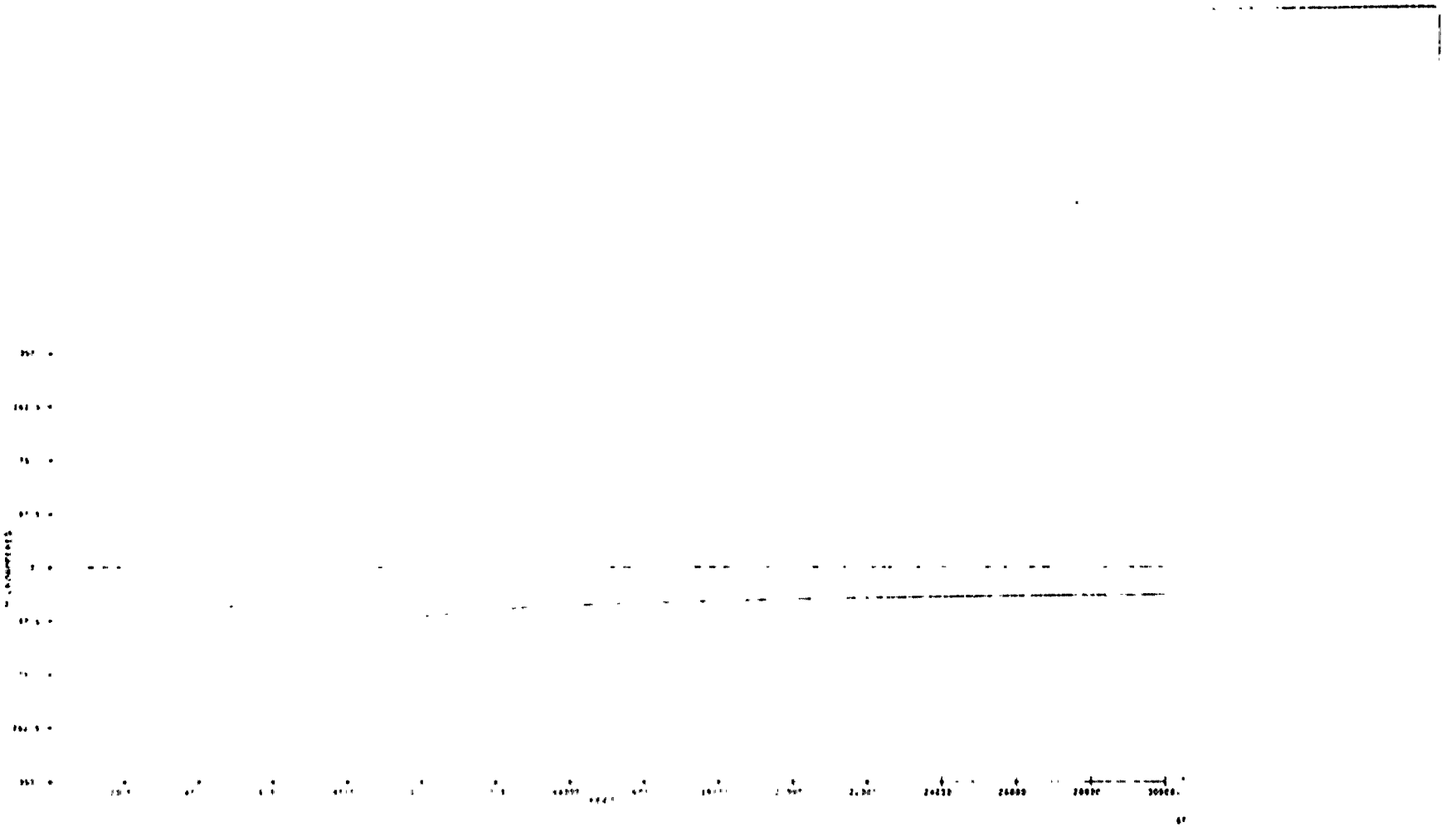


Figure 6F. Capture Effect Array, Flyability Run, Upgrade, Dropoff and Upgrade

Looking at the level flight runs first, Figures 6A, 6B, and 6C, we see that the null reference antenna data exhibits no zero cross over in the range considered (though there is a probable zero cross over at an elevated glide path angle of 3.7°; in contrast to this the sideband reference antenna has two zero cross overs in the same range, one at about 2.1° and the other at approximately 2.5° (and another probable zero crossover at about 3.7°) to produce a highly non linear distorted course; the capture effect antenna appears to have two zero cross overs one at 1.5° and another at 3.6°.

The flyability results are shown in Figures 6D, 6E, and 6F. The null reference data (Figure 6D) reveals a strong fly up signal of about 155 microamperes which is equivalent to almost 3/4°, which is just the angle at which the two separate pieces of ground slope upwards (see Figure 6). Clearly, to the null reference antenna, this type of terrain appears as a simple upslope.

Interestingly, the sideband reference results (Figure 6E) for this type of terrain are even poorer than the preceding for the null reference antenna.

The best performance is exhibited by the capture effect antenna whose results are depicted in Figure 6F. There is a fly up signal over the flight path whose peak-to-peak excursions range from 46 microamperes to 90 microamperes, about half that of the null reference antenna. The terrain does not appear as a simple 3/4° upslope to the capture effect antenna which would have then produced the same 155 microampere excursion as it did for the null reference antenna (see for example, the results for the simple upslope pictured in Figure 3).

3.6.1 Adjusted Antenna Element Heights

Figures 6G, 6H, 6I, 6J, 6K, and 6L exhibit the results for the terrain of Figure 6 after the antenna element heights have been adjusted to provide a 3° glide path. This 3° glide path angle was determined as the arithmetic mean over the distance between the middle marker and four miles from the threshold. The adjusted heights of the elements are given in Table 4.

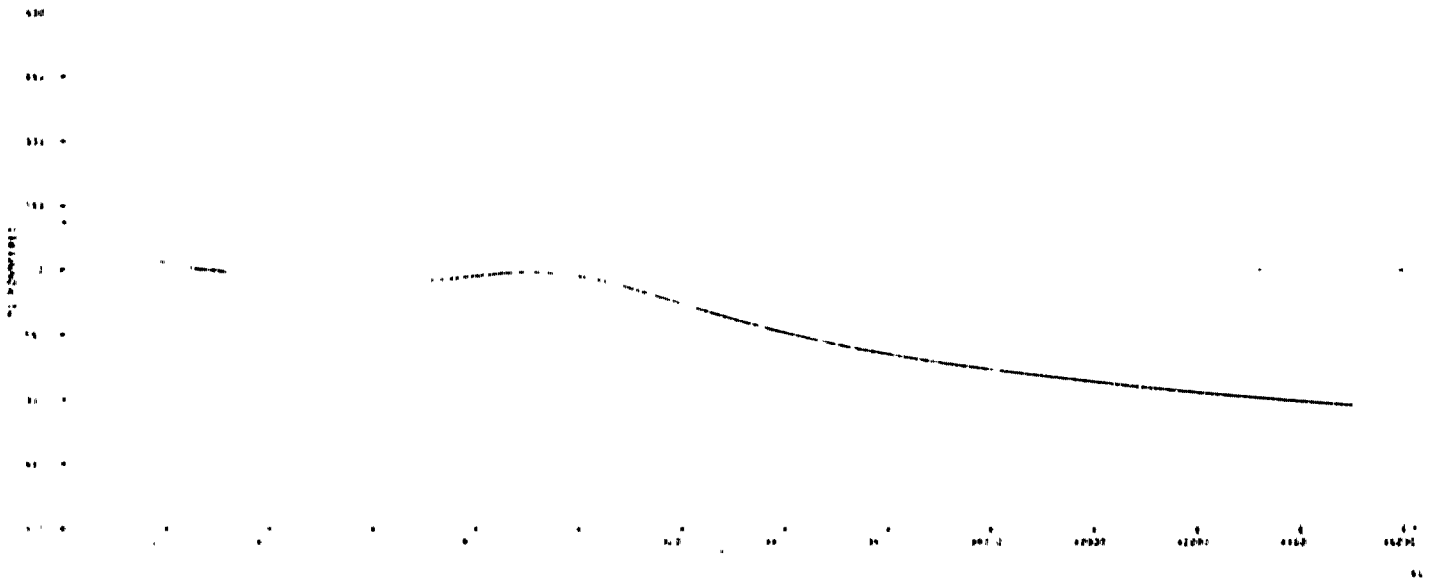


Figure 6G. Adjusted Null Reference Array, Level Run Flight, Upgrade, Dropoff and Upgrade

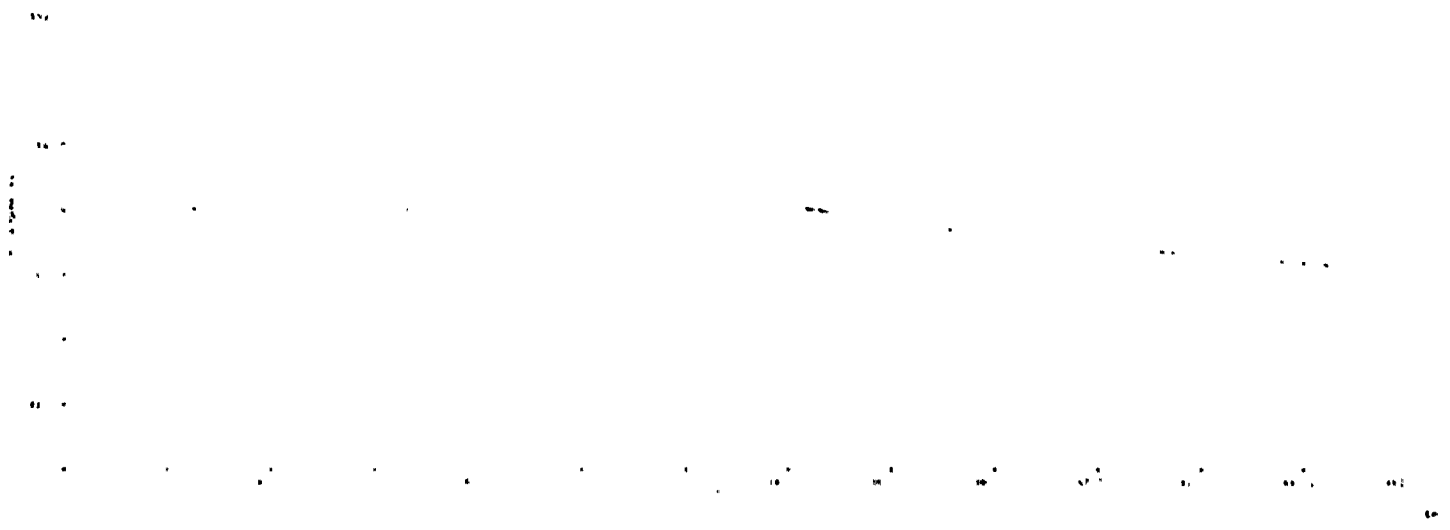


Figure 611. Adjusted Sideband Reference Array, Level Run Flight, Upgrade, Dropoff and Upgrade

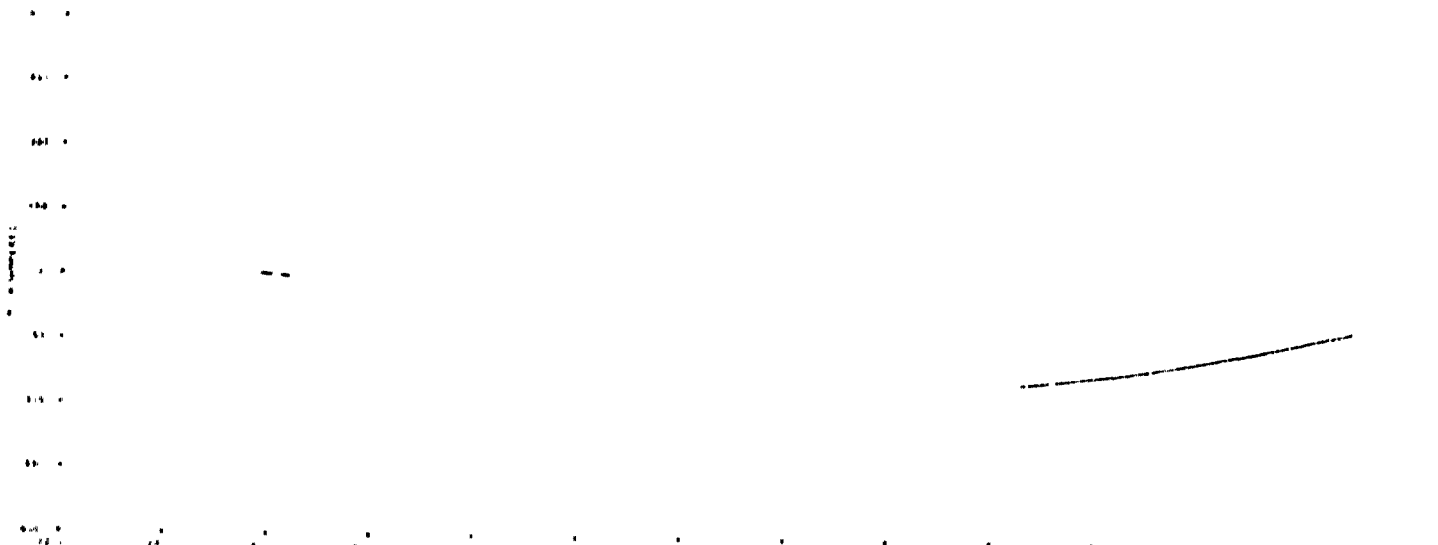


Figure 61. Adjusted Capture Effect Array, Level Run Flight, Upgrade, Dropoff and Upgrade

Figure 63. Adjusted Null Reference Array. Flyability Run, Upgrade Dropoff and Upgrade

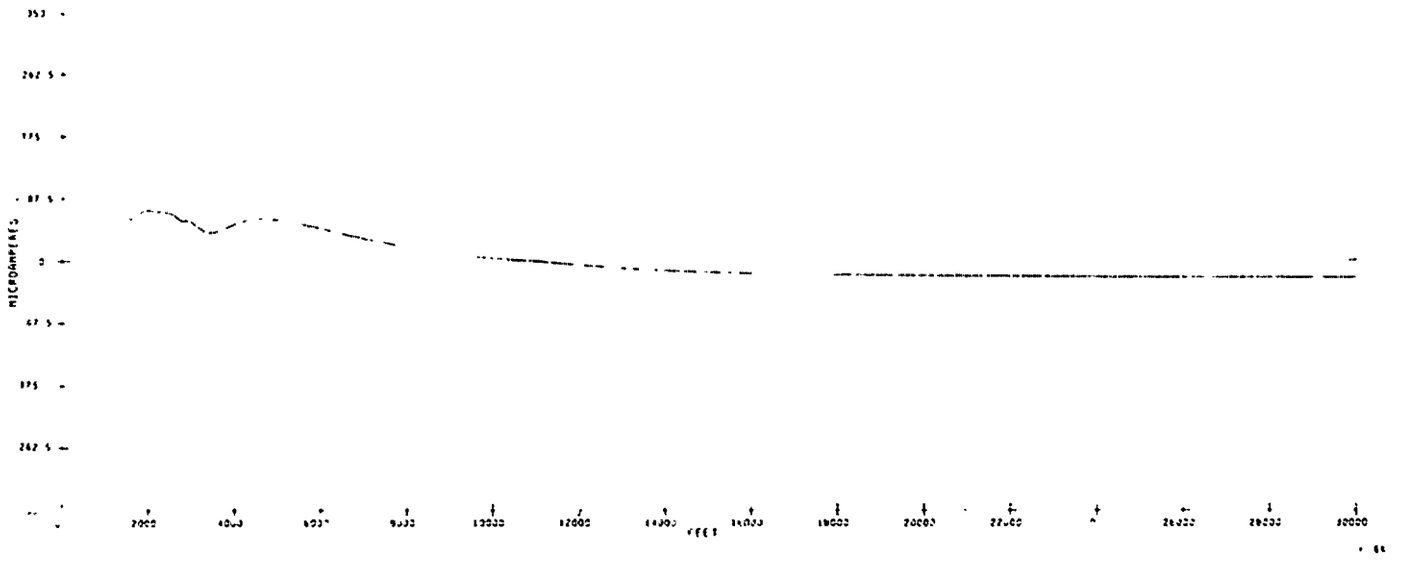


Figure 6K. Adjusted Sideband Reference Array, Flyability Run, Upgrade, Dropoff and Upgrade

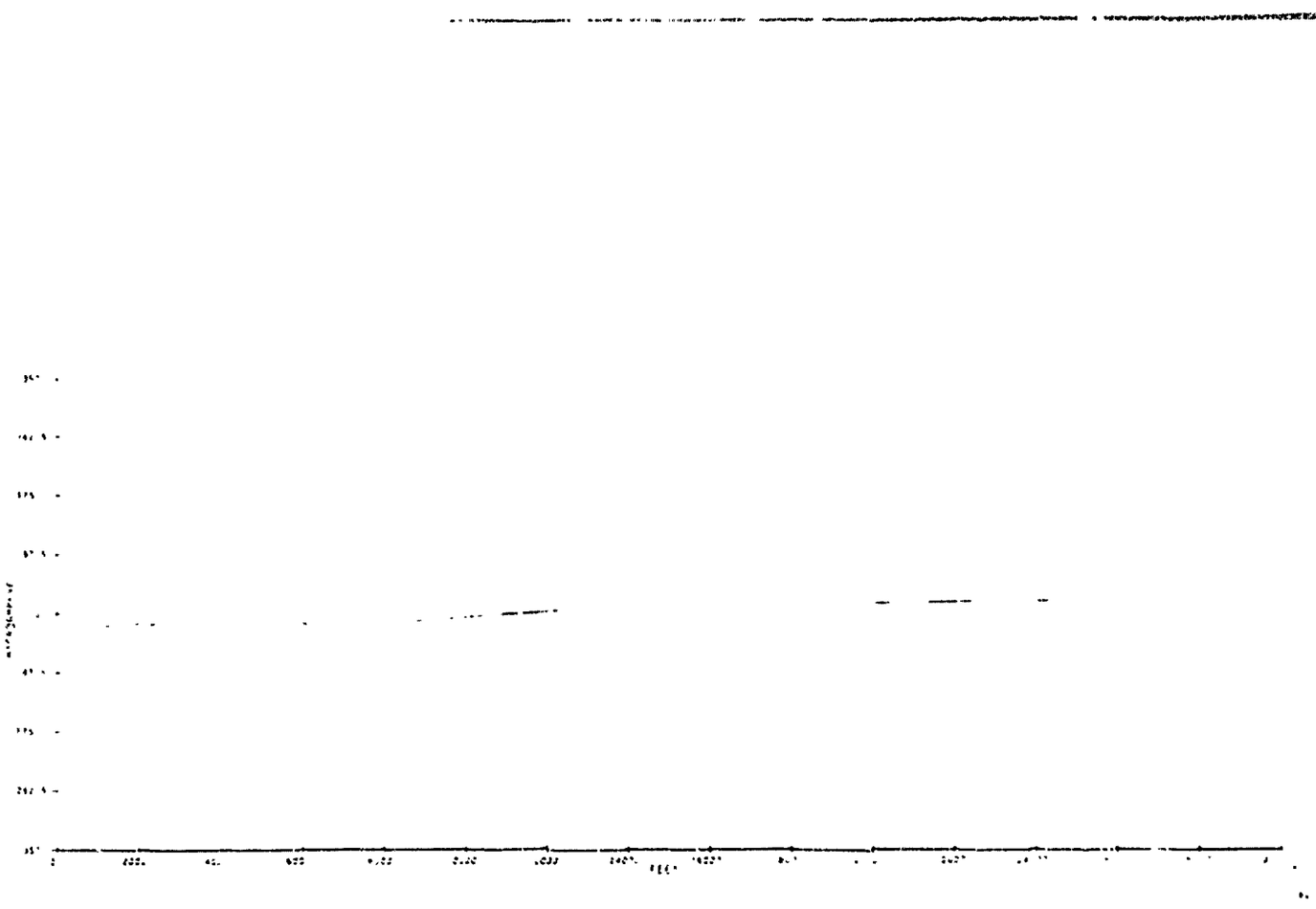


Figure 6L. Adjusted Capture Effect Array, Flyability Run, Upgrade, Dropoff and Upgrade

TABLE 4.

	Original Positions (feet)			New Positions (feet)		
	Lowest	Middle	Highest	Lowest	Middle	Highest
Null Reference	14.33		28.66	19.28		38.55
S.B. Reference	7.17		21.5	9.87		29.61
Capture Effect	14.33	28.66	42.99	16.48	32.97	49.45

The level flight results with these re-adjusted antenna element heights are shown in Figures 6G, 6H, and 6I. These level flight results still show considerable deviation from the ideal; with course linearity, in all three cases, distorted, though the null reference antenna data (Figure 6G), does exhibit the correct zero cross over at 3°.

The sideband reference level flight results (Figure 6H) exhibits no less than three zero cross over points within the range considered here (20,000' to 46,000'). Two of these zero crossings (one at about 3° and the other at about 2°) are in the right direction, which therefore could present a serious problem to the pilot. These results indicate that it is possible to fly a zero CDI course at the incorrect glide angle using a sideband reference antenna over this terrain.

The level flight values produced by the capture effect system are shown in Figure 6I. The zero crossing here is at approximately 2.8°.

The flyability of the course has been dramatically improved in all three cases with the new re-positioned antenna element heights. The null reference antenna results, shown in Figure 6J, has excursions between -20 microamperes and +9 microamperes (compared to 155 microamperes before re-positioning). This is considerably better than the sideband reference results (Figure 6K) which could not be corrected to give less than peak-to-peak microampere excursions of -73 to +25, and even somewhat better than the capture effect antenna results (Figure 6L) which show excursions

of between -19 and +25 microamperes after re-positioning of the antenna element heights.

It is interesting that for this type of terrain, consisting of two upslopes and a discontinuity, it has still been possible to correct the null reference antenna to produce results at least as good as those produced by the capture effect antenna. This will be the case, in general, whenever the terrain consists of simple up or downslopes.

3.7 HILL TERRAIN

The final terrain configuration to be discussed is depicted in Figure 7. The terrain consists of 3000 feet of flat terrain followed by an upgrade of 5° extending for another 2000 feet. The null reference data are shown in Figures 7A and 7D. The level flight results (Figure 7A) show a zero crossing point which is shifted about 1000 feet toward touchdown, equivalent to an elevation of the glidepath to 3.12°.

The flyability results (Figure 7D) reveal a strong fly up indication of 67 microamperes over the course from 30,000 feet to about 9000 feet from touchdown. This is followed by several very strong fly down indications, the highest of which occurs approximately 5500 feet from touchdown with a peak value of -182 microamperes.

The sideband reference results are shown in Figures 7B and 7E. The level flight data (Figure 7B) shows a cross over precisely at the 3° glide path angle, though an additional false cross over occurs at 1.6° (about 43,000 feet from touchdown for the 1200 foot high level flight). The flyability data (Figure 7E) reveals an almost distortion-free course until about 18,000 feet from touchdown. However, as the aircraft approaches closer, a gradually increasing fly up signal is received which peaks at 87 microamperes at about 8500 feet from touchdown. This is followed by even stronger fly down signals, the largest of which peaks at -165 microamperes about 5500 feet from touchdown.

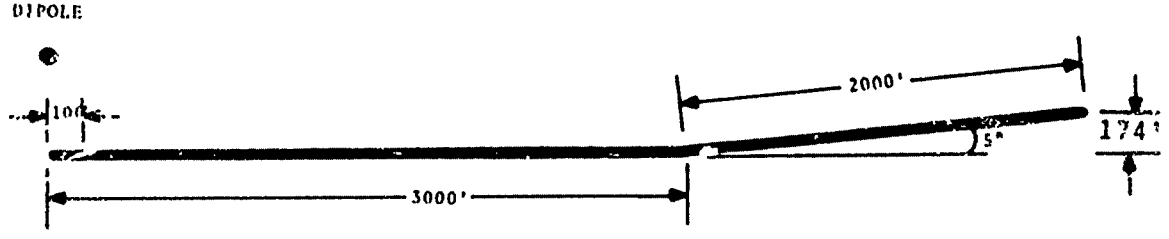


Figure 7. Hill (5° Upgrade)

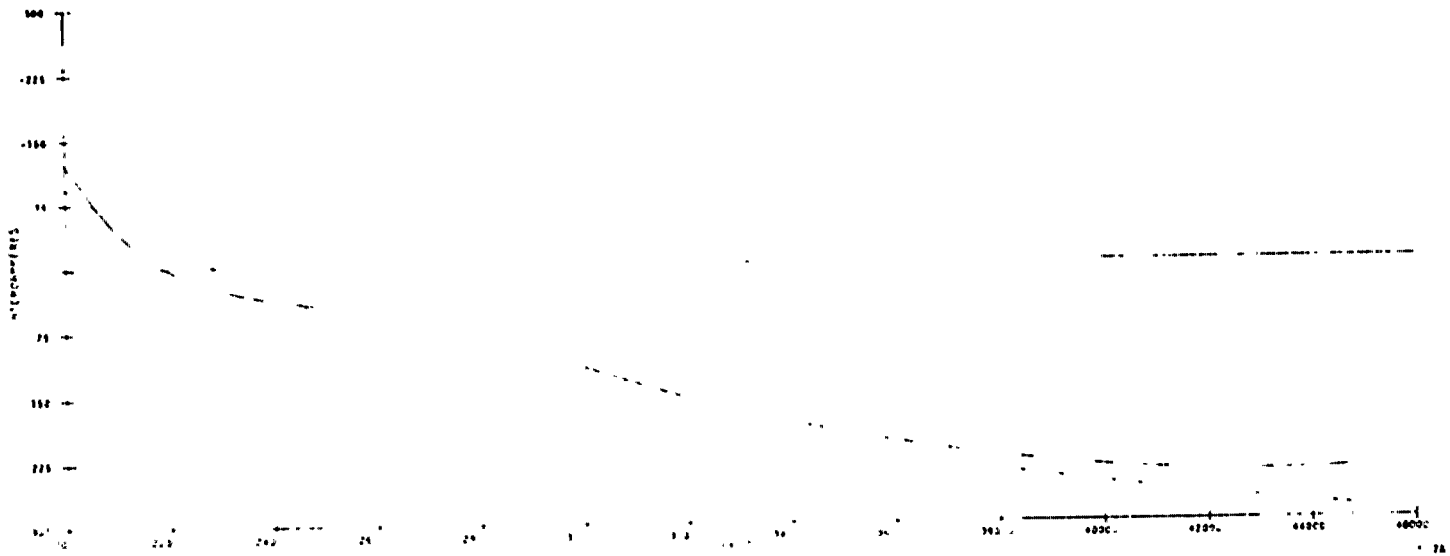


Figure 7A. Null Reference Array, Level Run Flight, Hill

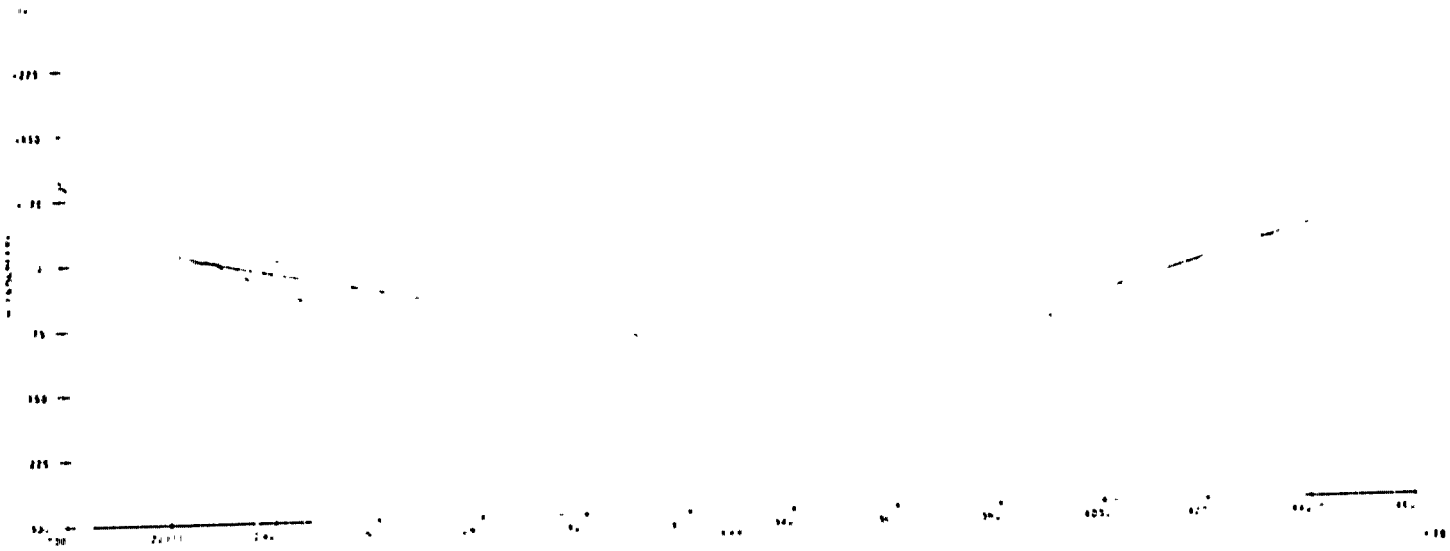


Figure 7B. Sideband Reference Array, Level Run Flight, Hill

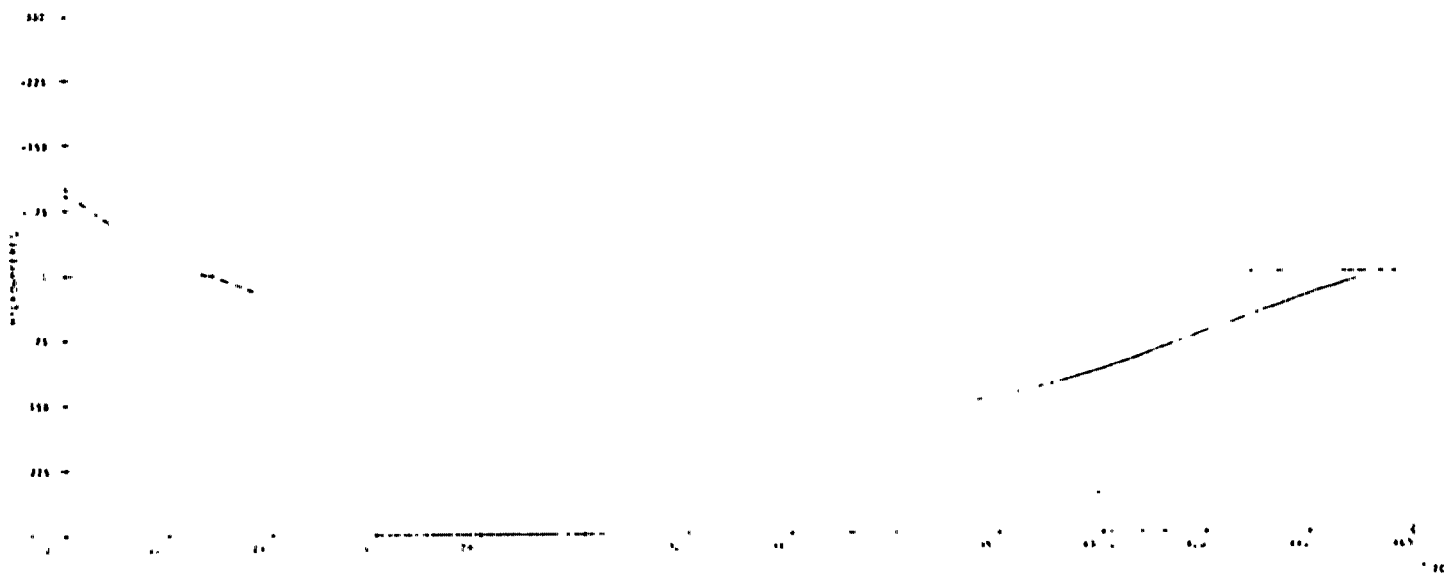


Figure 7C. Capture Effect Array, Level Run Flight, Hill

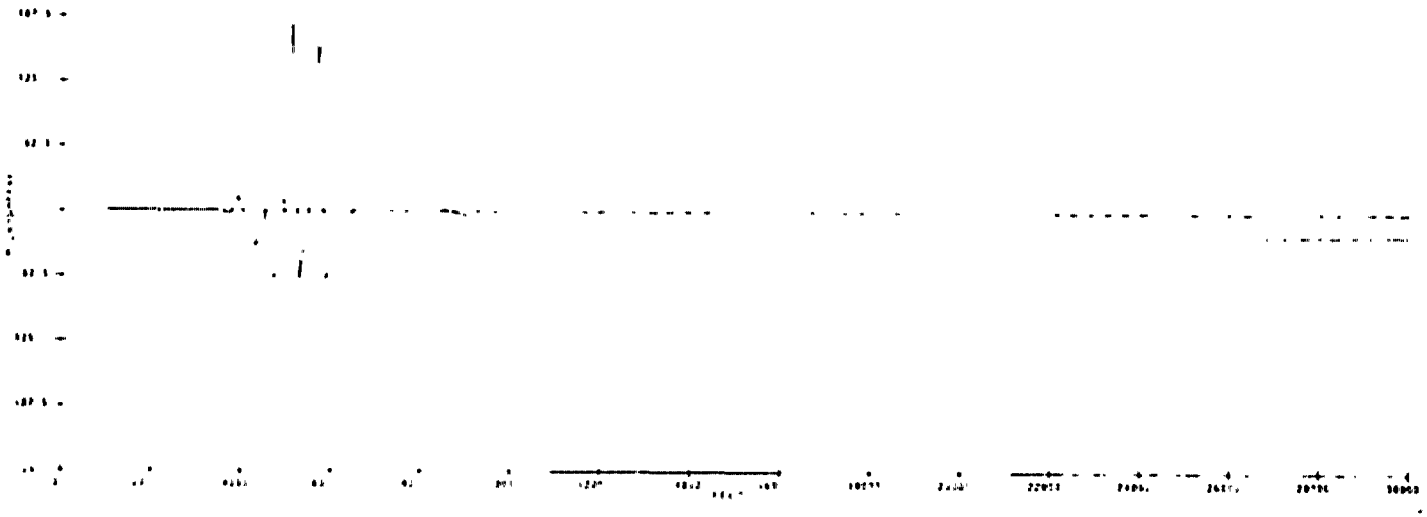


Figure 7D. Null Reference Array, Flyability Run, Hill

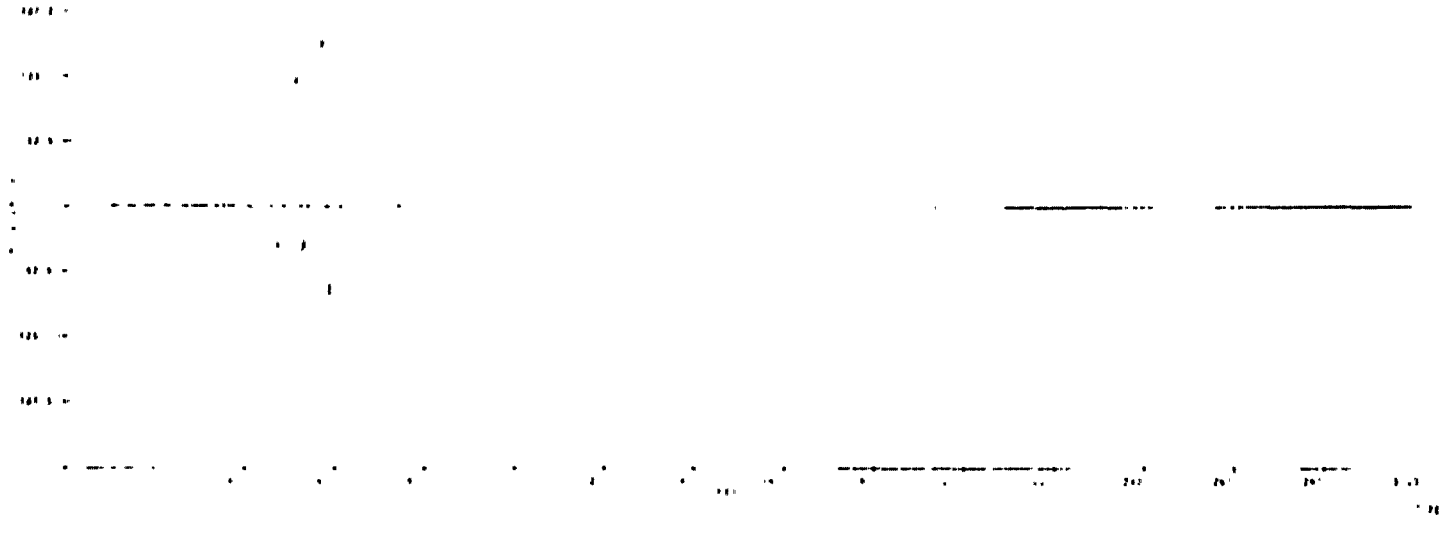


Figure 7E. Sideband Reference Array, Flyability Run, Hill

Figure 7F. Capture Effect Array, Flyability Run, Hill

The capture effect antenna system results are shown in Figures 7C and 7F. The level flight data (Figure 7C) exhibits a zero cross over which is very nearly at the correct 3° glide path angle, though here too, as in the sideband reference data, there appears to be a false cross over (at about 1.46°). The nominal glide path results (Figure 7F) show that the capture effect antenna system offers a decided improvement over the two previous antenna systems. There is a near zero CDI over most of the course, never exceeding 27 microamperes, from 30,000 feet until 8000 feet from touchdown. This mild fly up signal is followed by several fly down signals which, however, never exceed -45 microamperes (which is only about a quarter that of the other two systems). Clearly, for this type of terrain, characterized by flat ground followed by a mildly steep hill, only the capture effect system can produce an acceptable course structure. This is true even after the antenna element heights are adjusted to form a mean 3° glide path angle.

3.7.1 Adjusted Antenna Element Heights

This mean glide path angle was formed by re-positioning the antenna element heights as shown in Table 5:

TABLE 5.

	Original Positions (feet)			New Positions (feet)		
	Lowest	Middle	Highest	Lowest	Middle	Highest
Null Reference	14.33		28.66	14.64		29.28
S.B. Reference	7.17		21.5	7.22		21.7
Capture Effect	14.33	28.66	42.99	14.35	28.71	43.07

The results with this re-positioning of the antenna element heights are shown in Figures 7G, 7H, 7I, 7J, 7K, and 7L. The level flight data, Figures 7G, 7H, and 7I, are similar to the previous level flight data, which was to be expected with the modest change in the antenna element heights needed to obtain a mean 3° glide path angle.

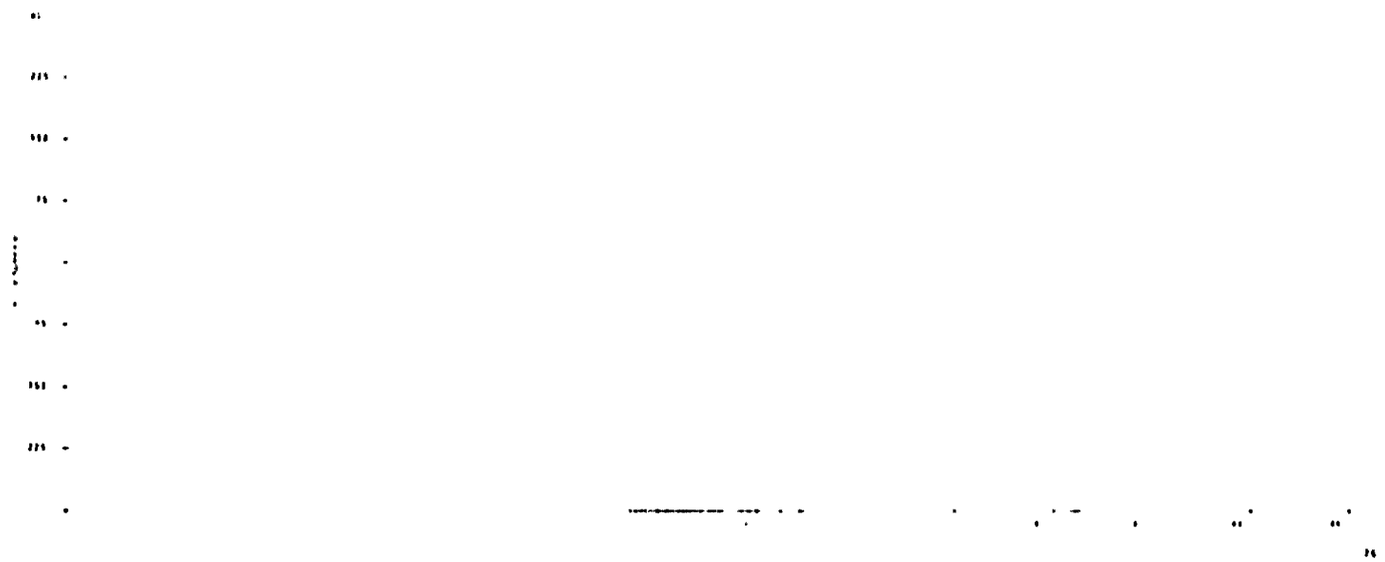


Figure 76. Adjusted Null Reference Array, Level Run Flight, Hill

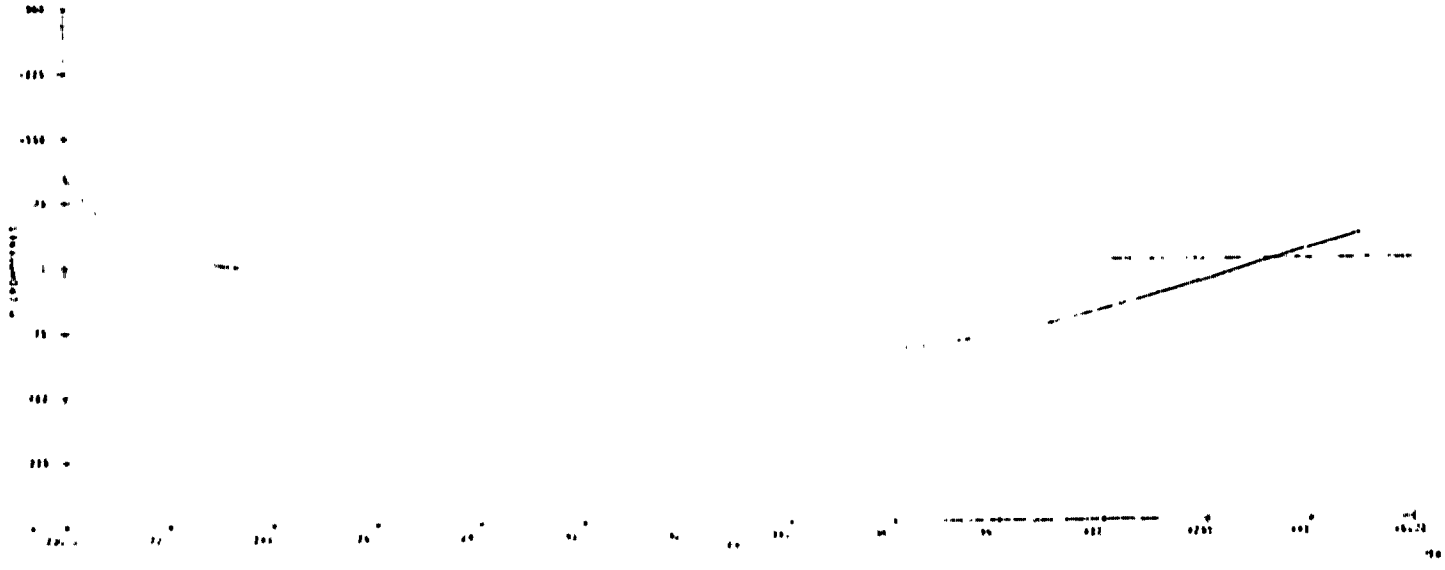


Figure 71. Adjusted Sideband Reference Array, Level Run Flight, Hill

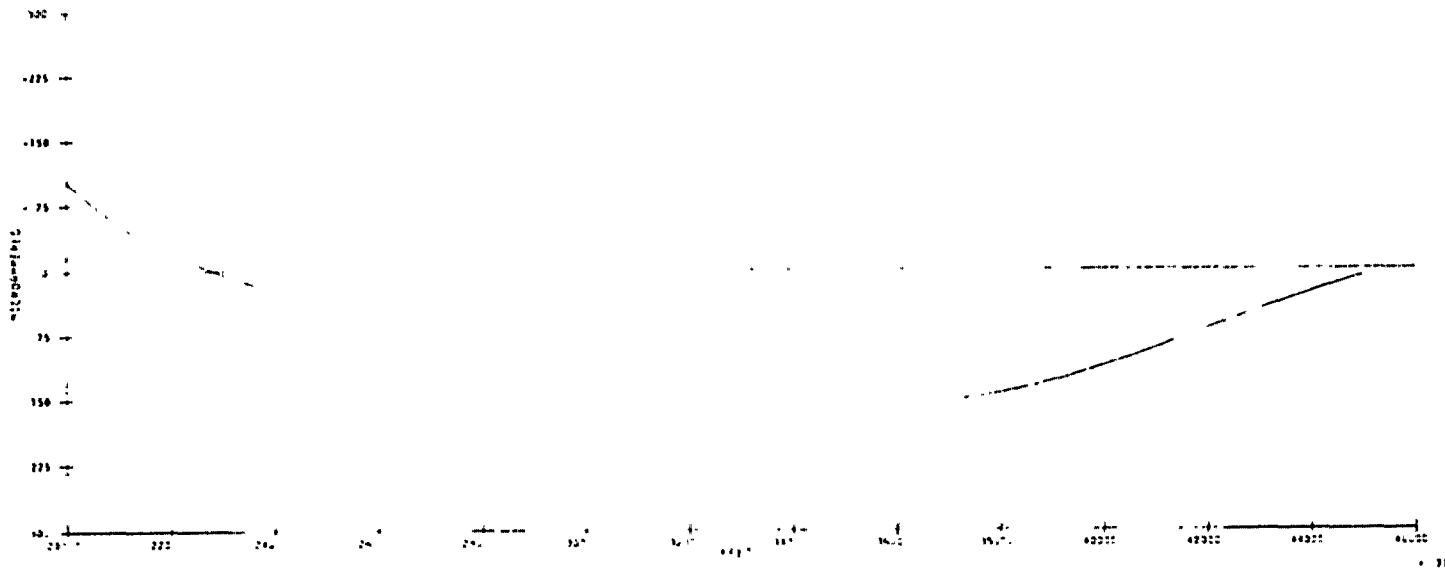


Figure 7I. Adjusted Capture Effect Array, Level Run Flight, Hill

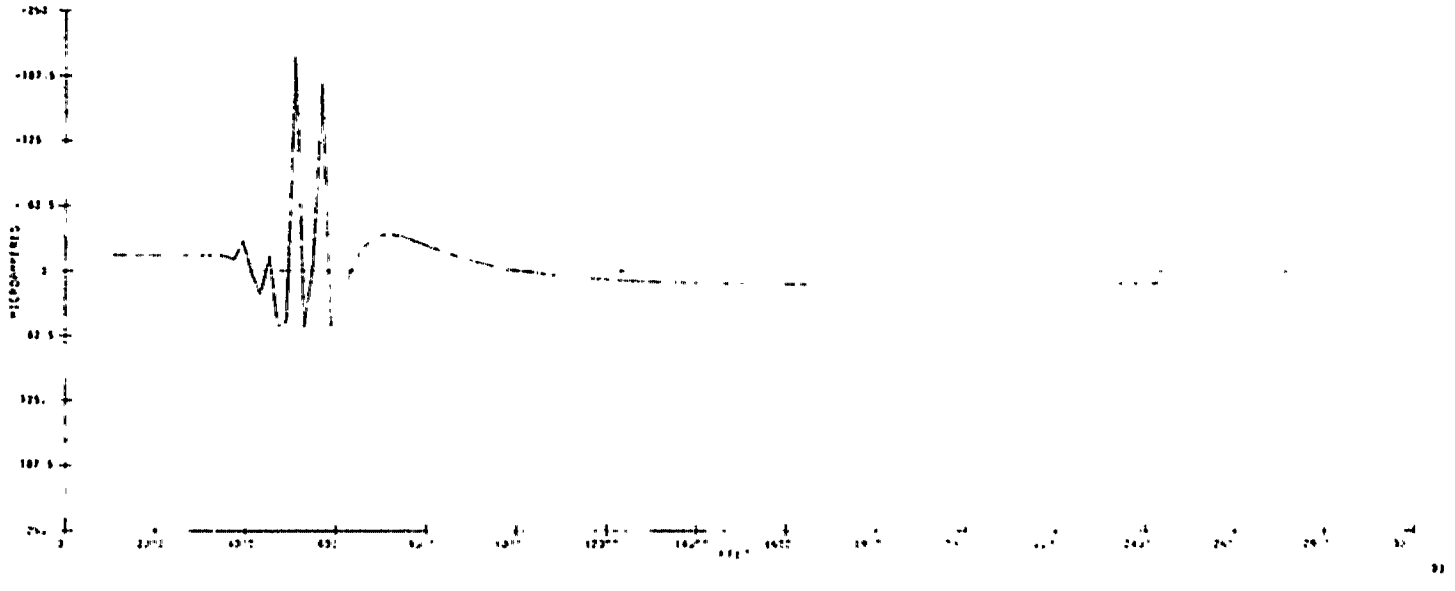


Figure 7J. Adjusted Null Reference Array, Flyability Run, Hill

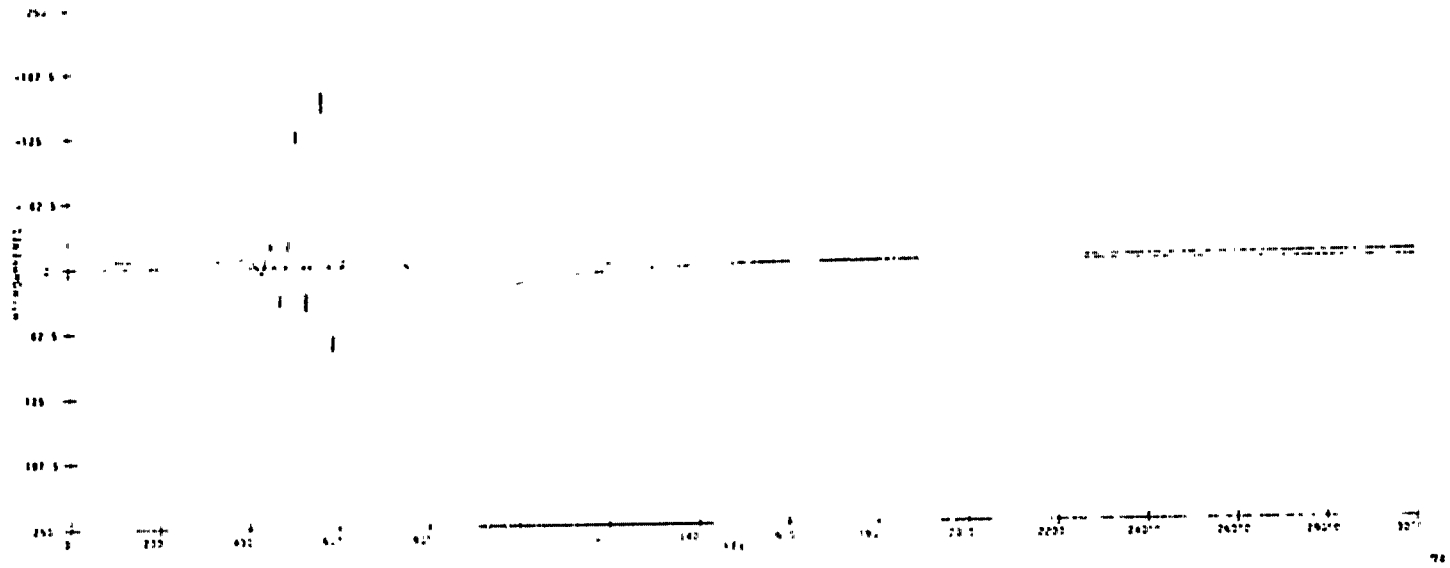


Figure 7K. Adjusted Sideband Reference Array, Flyability Run, Hill

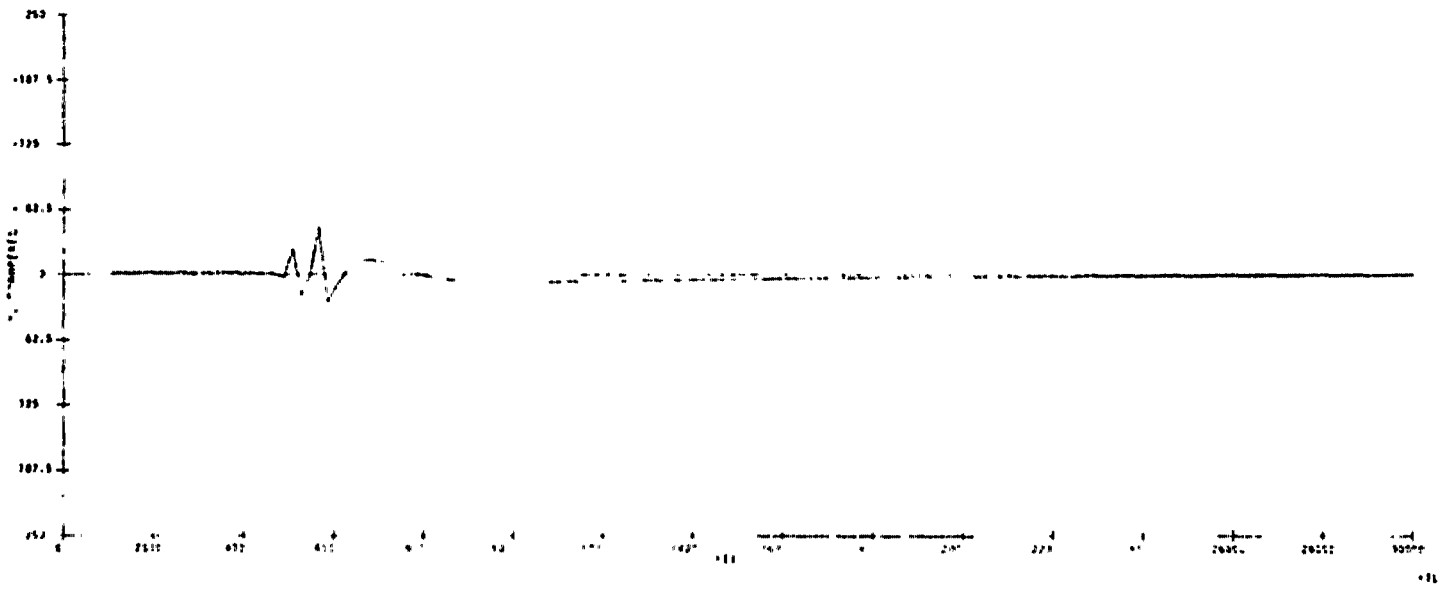


Figure 7L. Adjusted Capture Effect Array, Flyability Run, Hill

The flyability data are shown in Figures 7J, 7K, and 7L. With the null reference antenna (Figure 7J) there is less of a fly up indication after antenna adjustment than before (an almost uniform 56 microamperes as compared to 67 microamperes before the re-positioning) but larger fly down peaks (-208 microamperes as compared to -182 microamperes). Similarly, for the sideband reference antenna: the fly up signal decreased from a maximum of 87 microamperes to a maximum of 82 microamperes, but the fly down signal increased from -165 microamperes to -171 microamperes maximum. The course structure using the capture effect system remains essentially the same as before re-positioning.

As also found for the case of the terrain depicted in Figure 5, a simple re-positioning of the antenna element heights to obtain a mean 3° glide path angle over the distance between the middle marker and four miles out does not improve the course structure for the terrain of Figure 7. As before, here too, the original course structure showed both fly up and fly down excursions. In correcting the one, the other becomes worse. The only system capable of producing an acceptable course structure for this "hill" type terrain is the capture effect system.

PART II. USER'S MANUAL*

1. INTRODUCTION: DEFINITION OF INSTRUMENT LANDING SYSTEM

The ILSGLD program has been written to simulate certain terrain conditions which affect the glide slope portion of the Instrument Landing System. The ILS is used to provide signals for the safe navigation of landing aircraft during periods of low cloud cover and other conditions of restricted visual range. Separate systems are used to communicate vertical and horizontal information; the vertical system is called the "glide slope".

This system operates by the transmission of an RF carrier, amplitude modulated by two audio frequencies, beamed to approaching airborne receivers. In an instrumented aircraft, the glide slope receiver serves to demodulate the RF signal, amplify and isolate the corresponding audio signals and derive a signal to drive the ILS vertical display in the cockpit. The pilot, by reading the display, can determine if he is on course, above or below the glide path. These signals must be strong enough to cover a radius of 15 miles around the antenna.

The directional information is determined by the relative strengths of the transmitted sideband signals. The audio frequency modulations, which are fixed at 90 Hz and 150 Hz, are radiated in different angular patterns with respect to the intended glidepath. The "course" is defined as the locus of points where the amplitudes of the two modulations are equal. The display of a difference of the amplitudes (90 Hz and 150 Hz) of the sidebands is referred to as the Course Deviation Indication. Thus, the CDI is the pilot's indication as to what his altitude is relative to the glidepath. The CDI is measured in microamps. The actual course generated by any particular ILS installation will deviate from the ideal due to irregularities in the terrain. The deviation of the CDI, caused by these irregularities, from the ideal receiver reading at that point in space (e.g., on the glidepath a CDI reading other than 0) is the derogation effect.

*Part II is in actuality Section 4 of the report; accordingly, Chapters 1-5, Part II, are paginated as 4-1 through 4-16.

The glide slope system transmits an asymmetrical pattern by beaming a "carrier plus sideband" pattern and a "sideband only" pattern, the composite of which gives the desired effect.

2. ANTENNA PATTERNS

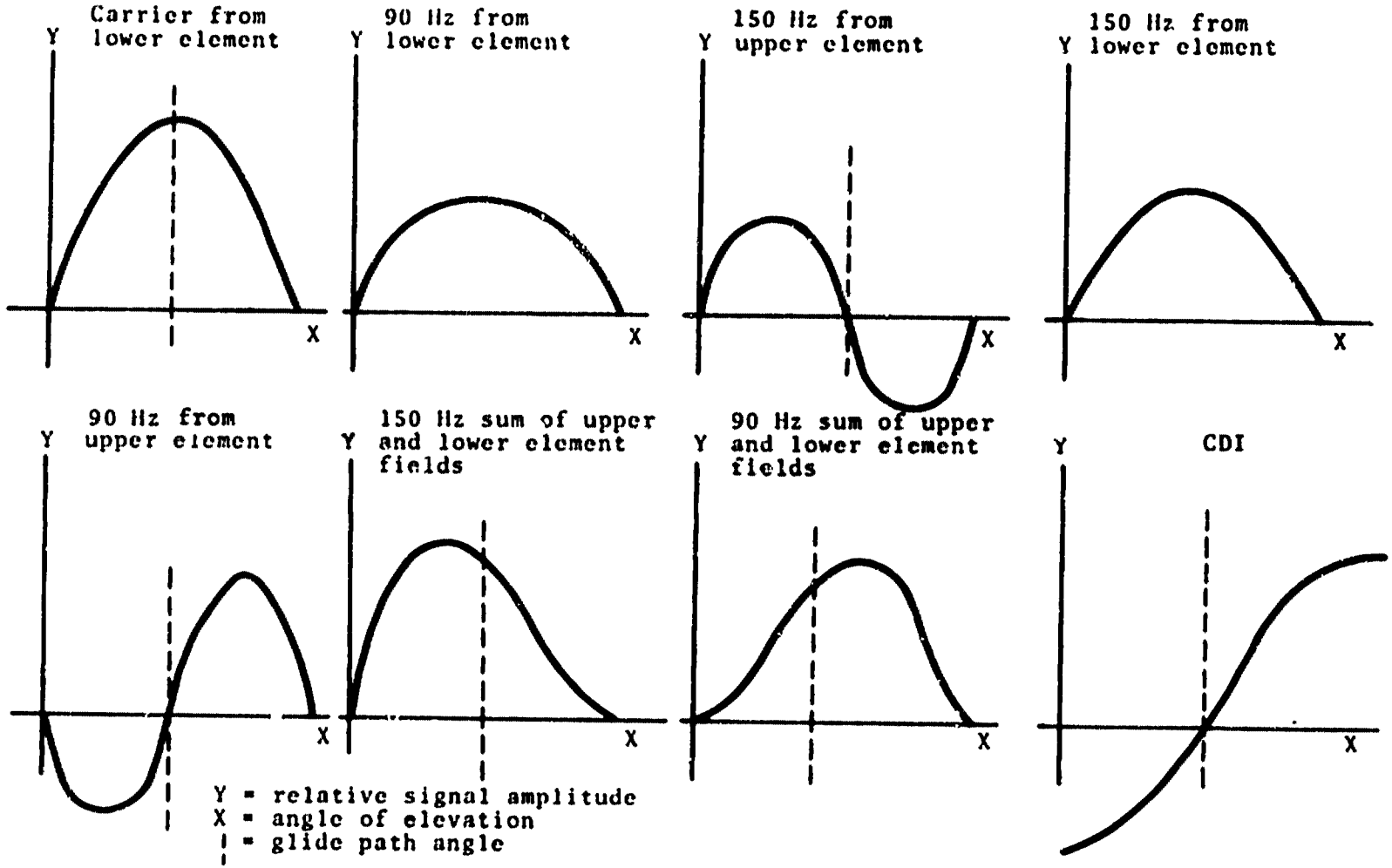
The proper angular variation of the transmitted 90 Hz and the 150 Hz modulation is achieved by the radiation of the two independent sideband patterns by the transmitting antennas. One pattern, the "carrier plus sidebands" (C+S) signal, is radiated in a symmetrical pattern; the other pattern, the "sidebands-only" (SO) signal, is radiated in an "anti-symmetrical" pattern relative to the prescribed glide angle (see Figure 8.)

The C+S signal is composed of a carrier wave and paired sideband waves at 90 Hz and 150 Hz. The sideband amplitudes are equal and represent a 40% modulation of the carrier wave (or a "depth of modulation" of 0.4) at both frequencies. The SO wave is a carrier wave that is equally modulated at 90 Hz and 150 Hz to the extent that it retains no pure carrier component.

The spatial modulation pattern obtained by combining the symmetrical C+S pattern with the "anti-symmetrical" SO pattern is illustrated in Figure 8. At a given receiver point the total signal is the C+S carrier plus the combined sideband amplitudes of the C+S and SO patterns. The sideband amplitudes are phased so that above the glide path the 90 Hz amplitudes add and the 150 Hz amplitudes subtract, while below the glide path, the 90 Hz amplitudes subtract and the 150 Hz amplitudes add.

Any angular deviation of the airplane's receiver from the correct course results in a "Difference in Depth of Modulation" (DDM) between the 150 Hz and 90 Hz signals. Since the strength of C+S and SO signals fall off at the same rate with distance from the transmitting antenna, the DDM is independent of range.

The antenna patterns are generated by using arrays of one or more elements in combination with the ground as reflector. The effect of an ideal ground plane on a single element is as though there was an "image" element located below the ground and radiating equal power to the real element but with opposite phase. In a glide slope array there will be two or more elements radiating different signals to give the desired combined antenna pattern.



Y = relative signal amplitude
X = angle of elevation
| = glide path angle

Figure 8. Antenna Patterns for Null Reference Antenna

(Note that this means that a glide slope array is defined by giving, for each element, its location and complex amplitude of the carrier and sidebands.) However, the real ground is not an ideal plane. This has the effect of distorting the element patterns and results in a derrogation of the glide slope system performance.

3. SIMULATION DESCRIPTION OF ILSGLD

The ILSGLD simulation program allows the user to study the effects of various ground shapes and antenna types. Using this program, the user may determine what antenna systems will give acceptable performance with a particular ground configuration or what ground shapes cause problems with various antennae.

The program uses a ground description, an antenna description, and a set of spatial coordinates of the receiver location as input. The program calculates and outputs for each receiver location, the CDI at that point both from the "real" ground and from an "ideal" (perfectly conducting and flat) ground plane. In addition, the effects of the electrical and mechanical inertia are included and "dynamic CDI's" are also output for both cases.

The inputs for ILSGLD are data files prepared by the program FMAKE. The outputs from ILSGLD are in data files which are used as input to a third program GLDPLT. GLDPLT produces graphical outputs of the various CDI's. The description and usage of these programs are described in succeeding sections.

The ILSGLD simulation makes certain simplifying assumptions. These include:

a. perfectly reflecting ground surface

b. far field scattering - all scattering from points on the ground surface is assumed independent of all other points, thus multiple reflections and near field interactions are ignored

c. noise free environment

d. relative field strengths - the absolute field strengths involved are not calculated. Thus, while the CDI's can be calculated in microamperes, the absolute electric field intensities are not ascertained

e. idealized receiver model

f. geometrical shadowing - the shadowing of one portion of

the ground on another is done by straight ray approximations assuming a total cutoff with no diffraction.

g. antenna elements are assumed to be simple dipoles.

3.1 METHOD OF SIMULATION

An antenna element is described by giving its x-, y- and z-coordinates and the complex amplitudes of its radiated amplitude at the three frequencies (carrier, 150 Hz, and 90 Hz sidebands). The ground is broken up into strips; these strips have an infinite width and a finite length. The infinite extent is parallel to the y-axis, that is at a right angle to the runway centerline. Thus, a ground strip is described by giving the x- and z-coordinates of the leading and trailing edges of the strip. A receiver location is described by giving its time, x-, y- and z-coordinates.

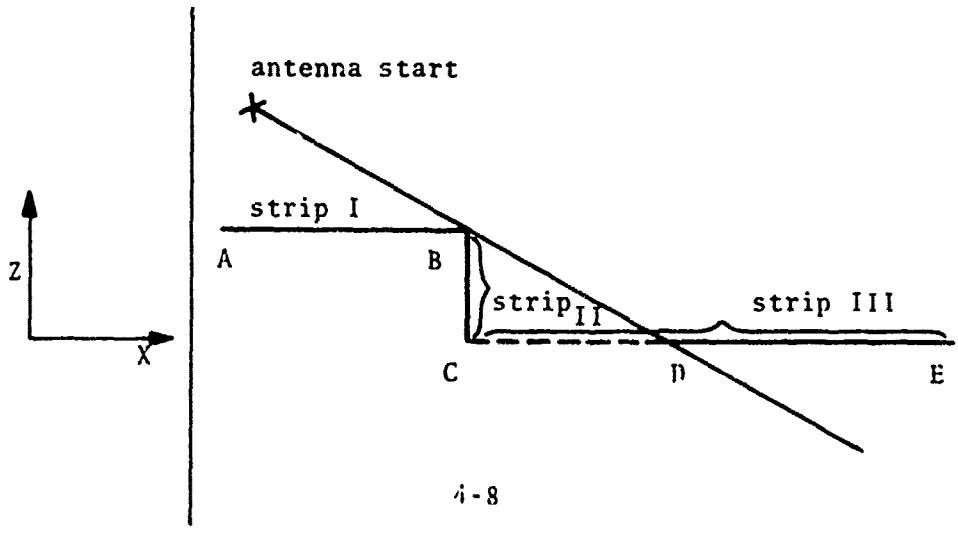
The basic part of the simulation consists of calculating the field at a receiver location. This field is caused by the power radiated from an element and reflected from a strip. A detailed description of the method of calculation has been given previously (Part I). The receiver field can be expressed as a complex gain factor times the radiated antenna field. This gain factor is expressed as a double integral over the strip. The integration along the infinite extent (y-axis direction) was approximated by using the stationary phase method. The resulting single integral is solved by a modified trapezoid rule. The trapezoid rule is used with the spacing between sample points adjusted for the derivative of the integrand.

Thus, for a given receiver location, the program takes an antenna element and calculates the "gain factor" for each ground strip, multiplies by the radiated power, and sums the three complex field intensities for all ground strips. The direct field of the element at the receiver is then added. This process is repeated for all elements, giving the total field at the receiver. Using an idealized receiver model the voltages at the output of the receiver are calculated and the CDI derived. This is then repeated for the next receiver location by summing the fields over all the

elements and over all the strips. For comparison purposes, the "ideal" ground plane field is also calculated and summed separately. The CDI's due to actual and idealized ground conditions may then be compared. Finally, a second pair of CDI's are derived by using a first order difference equation with the instrument time constant and the time differ.ce from the last point, thus simulating the "inertia" of the ILS glide slope receiver and display (so called "dynamic" CDI).

At each receiver point, an output record is generated in file STRIP.DAT consisting of the x-, y-, z-, and time coordinates of the receive plus the four CDI's.

If the terrain is sufficiently irregular, part of the energy radiated toward a point on the ground may be intercepted by another piece of the ground closer to the antenna. This shadowing is complex including, as it does, diffraction as well as reflection. This is approximated in the simulation by using ray optics; that is, the shadow is assumed to have no diffraction at the edges and a zero field amplitude inside the shadow. The program does this by assuming the ground is continuous, i.e. the far edge of one strip is the near edge of the next, and keeping track of the "furthest" (in angular sense) edge. If part (or all) of the next strip is "below" that edge then that part (or all) will not be included in the trapezoid integration. For example in the sketch below



all of strip I, none of strip II and that part of strip III between D and E will be included in the integration.

For the receiver antenna a "semi" directional antenna is assumed; that is, only the incident fields from the front half-sphere around the receiver are included. This is as though an omni-directional antenna was used but blocked by the fuselage from receiving signals from the direction of the tail. This is done in the program by stopping the summation of fields over the ground strips at a point directly below the receiver.

The back half-plane is assumed to be an ideal flat horizontal reflector of infinite extent. The field from this is included by adding the "gain factor" for this as an initial strip to that calculated by integrating over the "real" strips.

3.2 OPERATION

ILSGLD assumes the ground description is a file called GRND.DAT, and that the receiver locations are in a file called PATH.DAT. The user starts the program and then inputs the name of the file containing the antenna description. The simulation will be run, and the output will be found in file STRIP.DAT.

3.3 CONCLUSION

ILSGLD represents an initial effort at glide slope landing system simulation. It has been exercised with simple test cases. Two possible areas for future work include:

1. terrain variation perpendicular to runway centerline direction - the ground does not usually have a constant profile along the y-direction as is presently assumed;
2. varying conductivity - the physical ground surface is not necessarily the "surface" as seen by the radio frequency fields as is presently assumed.

4. FMAKE PROGRAM DESCRIPTION

FMAKE is a file generation program used to create input files for ILSGLD. It is designed to be used interactively. The user starts by running the program. The program will respond by typing:

INPUT SWITCH:

The user then types in a single character switch, followed by a <CR>, for the file he wishes to generate. The program will then respond with a request for the input required for that file. If a blank is used as the input switch the program will terminate. If any character other than the ones explained below are used an error message will be given. After each file is generated, the program will return to the switch input point thus allowing the user to generate the data files for many simulation runs in one sitting.

(N.B. All units are in feet unless otherwise stated)

4.1 SWITCH: Y

The program will type:

INPUT YO, LAMBDA:

The user then inputs in free field format the y-offset (i.e. the y-coordinate) of the antenna elements and the wave length of the carrier, followed by a <CR>. The y-offset is the distance from the base of the antenna to the centerline of the runway. As this information is required for both the antenna description and the flight path it is input with a separate switch to avoid repetition.

4.2 SWITCH: G

This is used to input the ground description. The program will respond with:

INPUT GROUND FILE NAME:

The user then inputs a five(5) character name for the ground description file, followed by a <CR>. ILSGLD requires the ground

file to be called GRND.DAT (The .DAT extension is a system default). FMAKE allows the user to generate several ground files with different names at one sitting. Then by using system renaming commands a single batch job may be set up that will run many simulations without further user interactions.

The program will then type:

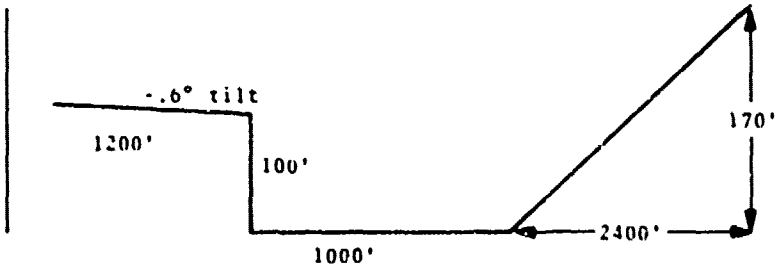
INPUT GROUND LABEL

The user then inputs up to 40 characters to be used as a label for this ground description. This label is carried in the ground description file and will be placed in the output file by ILSGLD. This allows the GLDPLT program to label the plots with the ground description. This is necessary if a batch job generates plots from more than one simulation.

The program will then type:

INPUT GROUND SEGMENTS. STARTING FROM ANTENNA, GIVE CONSECUTIVELY EITHER X AND Z INCREMENTS, OR THE LENGTH AND ANGLE FROM HORIZONTAL IN DEGREES, SEPARATED BY A ZERO. HIT CARRIAGE RETURN FOR END OF DATA, OR IF THERE ARE NO MORE STRIPS.

The user inputs ground strip end points in either Cartesian or polar increments using two or three fields respectively. These are input in floating free field format followed by a <CR>. The first point is taken relative to the origin and is the near edge of the closest strip to the antenna. The second point is the far edge of the first strip and the near edge of the second strip. This second point is relative to the first. This will continue for additional strips until a <CR> is hit with no data, at which point the program will return to the switch input. For example to input this profile:



The input would be

0.,0.

1200., 0., -.6

0., -100.

2400., 170.

There is a maximum of 20 strips allowed in both FMAKE and ILSGLD. This is determined by array sizes and could be changed if desired.

4.3 SWITCH: P

This is used to generate a flight path file. The program will respond:

INPUT FLIGHT PATH FILE NAME:

The user then inputs a five(5) character file name (the name must be exactly 5 characters). ILSGLD requires the flight path to be in a file called PATH.DAT (for explanation of multiple files see SWITCH:G). The program will then type:

INPUT FLIGHT PATH TITLE:

The user then inputs a title, using up to 40 characters, for the flight path. This is used as a label on the plots output by GLDPLT. The program will then type:

INPUT FLIGHT PATH TYPE:

The user has a choice of two flight path types, linear or hyperbolic. For a linear flight path, type a <CR>; for a hyperbolic path type a 'G' followed by a <CR>. When it is a linear flight the program will respond:

INPUT X0, Y0, Z0:

The user then inputs the x-, y-, and z-coordinates of the first receiver point in free field floating point format followed by a <CR>. The program will respond:

INPUT XF, YF, ZF:

The user then inputs the final receiver location in the same way. The program then types:

INPUT # OF POINTS, VELOCITY, TIME CONSTANT:

The user then inputs the total number of receiver locations desired in integer free field format, followed by the velocity of the aircraft in feet/sec. in floating point free field and the time constant in seconds (usually 0.4) used for the "inertia" of the receiver in dynamic simulation. The program will then generate the data file and return to the SWITCH POINT.

The actual ideal surface of zero CDI is a hyperboloid of two sheets whose axis of rotation is parallel to the z-axis and passes through the antenna. For comparison purposes it is convenient to have the aircraft travel along this surface and see how the real CDI deviated from 0. If the glide path is used for linear flight in the near field (between threshold and antenna) large CDI's will occur because of the hyperbolic shape. The program will allow the user to generate a hyperbola which is the intersection of the 0 CDI surface and the plane containing the runway centerline parallel to the z-axis. To do this the user types a 'G' for the flight path type. The program will respond:

INPUT X0, XF, H:

The user inputs these in floating point free field format followed by a <CR>. X0 is the x-coordinate of the initial receiver point (Y0 is zero and Z0 is specified by the hyperboloid), XF is the x-coordinate of the final receiver point. H is the height of the main carrier element in the antenna array. The program will then respond:

INPUT # OF POINTS, VELOCITY, TIME CONSTANT

These are input as above. The program will generate the file and return to the switch point.

4.4 SWITCH: A

This switch is used to generate the antenna description file. The program will respond:

INPUT ANTENNA FILE NAME:

The user inputs the 5 character file name. The program will type:

INPUT ANTENNA DESCRIPTION:

The user inputs a <40 character antenna description to be used as a plot label. The program will then type:

INPUT ELEMENT VALUES:

The user then types in, in free field floating format, a maximum of 8 fields followed by a <CR>. The fields have the following usage:

field #	usage
1	x-coordinate of element (usually 0)
2	z-coordinate of element (height)
3	real amplitude of carrier
4	imaginary amplitude of carrier
5	real amplitude of 150 Hz side band
6	imaginary amplitude of 150 Hz side band
7	real amplitude of 90 Hz side band
8	imaginary amplitude of 90 Hz side band

This element inputting is repeated for each element. After the last element is input an extra carriage return is typed. No y-coordinate is input for the elements. This is because nominally all the elements have the same y offset (the value input as Y0 under switch Y). However, a small offset correction is applied for near field correction. An explanation of this correction may be found in part I (see discussion preceeding Eq. (33)). This is automatically done by the program. As the first element input is assumed to have the correct offset, it will always have a value of Y0. Thus the main carrier element should be input first, for example, a null reference antenna was input as follows:

INPUT SWITCH: Y

INPUT Y0, LAMBDA: 300., 3.

```
INPUT SWITCH:  A
INPUT ANTENNA FILE NAME : NULL
INPUT ANTENNA DESCRIPTION
NULL REFERENCE ANTENNA
INPUT ELEMENT VALUES
0., 15., 1., 0., .4, 0., .4, 0.
0., 30., 0., 0., -.12. 0., .12, 0.
```

5. GLDPLT PROGRAM DESCRIPTION

GLDPLT is a plotting output program to graph the CDI information from ILSGLD. The user runs GLDPLT which then types:

INPUT FILE NAME AND AXIS TYPE:

The user then types in a 5 character (left-justified and blank filled to 5 characters) and two integer fields in free field format. The first integer is the switch for x-axis type and the second integer is the switch for the y-axis. The y-switch has two values, 1 and 2, the x-switch has three 1, 2, and 3; any other values will terminate the program.

The switches have the following usage:

y-switch=1	this plots the static CDI values
y-switch=2	this plots the dynamic CDI values
x-switch=1	this uses the altitude angle, in degrees measured from the origin of the receiver point as x-coordinate
x-switch=2	this uses the x-coordinate of the receiver as the x-axis
x-switch=3	uses the time in seconds, at the receiver point, as the x-coordinate.

After the input, a plot is generated and the program returns to the input and asks for the data for the next plot. The user can give the same file name to plot the data differently, or a new file name can be given. This would be done when multiple runs were done before plotting; the output file from each simulation run carrying its own name.

APPENDIX A

LISTING OF ILSGLD

```
ILSGLD.F4       F40     V20(14) 21-JUL-76       17:51   PAGE 1

  1                DIMENSION ILABL(8)
  2                DIMENSION IPTDAT(33)
  3                COMMON /PLOT/ BBP,BIMN,BIMX,BIFT,BILT,BYMN,BYMX,BYFT,BYLT,
  4               1BZMN,BZMX,BZFT,BZLT,BTMN,BTMX,BTFT,BTLT,
  5               2AIMN,AIMX,AIFT,AILT,ABMN,ABMX,ABFT,ABLT,
  6               3ADIN,ADIX,ADIF,ADIL,
  7               4ADBN,ADBX,ADBF,ADBL
  8                EQUIVALENCE (IPTDAT(1),ABP)
  9                IMPLICIT COMPLEX (C)
 10                DIMENSION X(20),Y(20),Z(20)
 11                DIMENSION CF1(20),CF2(20),CF3(20)
 12                IMPLICIT DOUBLE PRECISION (D)
 13                COMMON /SLC/PI,RF,RZ,RT,RSIZE
 14                REAL LAMBDA
 15                COMMON /GROUND/ N,X1(20),Z1(20),X2(0/20),Z2(0/20),IEL
 16                COMMON /ANT/AX,AY,AZ,LAMBDA,DAK,DPI
 17                COMMON /VAL/ NB,NI
 18           C
 19           C       THIS VALUE OF TWO PI IS INITIALIZED THIS WAY TO AVOID USING
 20           C BLOCK DATA
 21                DPI=6.283185307179586476
 22           C
 23           C       THIS OPENS THE OUTPUT FILE
 24                CALL OFILE(1,'STRIP')
 25           C
 26           C       THIS IS A DUMMY RECORD.  AFTER THE RUN IS FINISHED THE OUTPUT
 27           C FILE WILL BE REWOUND AND THE ACTUAL RECORD WILL BE WRITTEN
 28                WRITE(1) IPTDAT
 29           C
 30           C       THIS SUBROUTINE OPENS THE FLIGHT PATH FILE AND RETURNS WITH
 31           C THE FLIGHT PATH PLOT LABEL (ILABL) AND TIME CONSTANT (TAU)
 32           C THE FILE WAS SET UP WITH JOVPAK SO THIS SUBROUTINE AND INPUT ARE
 33           C USED TO FACILITATE MODIFACTIONS
 34                CALL IF(ILABL,TAU)
 35           1000 FORMAT(8A5)
 36                WRITE(1,1000) ILABL
 37           C
 38           C       THIS SECTION INITIALIZES SOME CONSTANTS
 39                ABP=0
 40           C
 41           C       THIS SECTION INPUTS THE GROUND STRIPS DESCRIPTIONS
 42                CALL IFILE(20,'GRND')
 43                READ(20,1000) ILABL
 44                WRITE(1,1000) ILABL
 45                READ(20) N,X1,Z1,X2,Z2
 46                CALL RELEAS (20)
 47           C
 48           C       THIS SECTION INPUTS THE ANTENNA FILE NAME TO BEUSED
 49           C AND THEN INPUTS THE ANTENNA ELEMENT DESCRIPTIONS
 50                WRITE(5,2001)
 51           2001 FORMAT(' INPUT ANTENNA FILE NAME:',$)
 52                READ(5,2000) ILBL
 53           2000 FORMAT(A5)
```

```
      CALL IFILE(30,ILSL)
      READ(30,1000) ILABL
      WRITE(1,1000) ILABL
      READ(30) LAMBDA,MEL,(X(I),Y(I),Z(I),CF1(I),CF2(I),CF3(I),I=1,MEL)
      CALL RELEAS (30)
      SORTEL=1./SQRT(2.*LAMBDA)
      TEMP=2.*LAMBDA
      BAR=DBLE(LAMBDA)
      BAR=DSQRT(BAR)
C
C     THIS IS THE MAIN LOOP FOR THE SIMULATION.  THE RECEIVER
C LOCATION IS READ IN BY INPUT.  THE DATA IS IN COMMON 'REC'
C THE INPUT BEING DONE BY JOVBS1.  IF THERE ARE NO MORE RECEIVER
C POINTS THE SUBROUTINE RETURNS TO 200.
301   CALL INPUT(0200)
C
C     THIS SECTION INITIALIZES THE COMPLEX AMPLITUDES FOR
C THE RECEIVED FIELD AS FOLLOWS:
C       CF1    CARRIER WITH 'REAL' GROUND
C       CF2    150 MZ SIDEBAND WITH 'REAL' GROUND
C       CF3    90MZ SIDEBAND WITH 'REAL' GROUND
C       CF11   CARRIER WITH 'IDEAL' FLAT GOUND PLANE
C       CF12   150MZ WITH 'IDEAL' GROUND
C       CF13   90 MZWITH 'IDEAL' GROUND
      CF11=(0.,0.)
      CF12=(0.,0.)
      CF13=(0.,0.)
      CF21=(0.,0.)
      CF22=(0.,0.)
      CF23=(0.,0.)
      R2=SQRT(PI+PI+PI+PI)
C
C     THIS LOOP IS OVER THE ELEMENTS OF THE ANTENNA
C THE COMPLEX FIELDS ARE SUMMED IN CF11,CF12 ETC.
      DO 3 IEL=1,MEL
C
C     THESE ARE THE LOCATION COORDINATES OF THE ANTENNA ELEMENTS
C AND CONSTANTS USED IN THE STRIP INTEGRATION
      AX=X(IEL)
      AY=Y(IEL)
      AZ=Z(IEL)
      DELX=BX-AX
      DELY=BY-AY
      DELZ=BZ-AZ
      DR=DSQRT(DELX+DELX+DELY+DELY+DELZ+DELZ)
      R=SNGL(DR)
      DR=DR+BAR
      ILOOP/DPI
C
C     THIS SECTION INITIALIZES  HR AND HI TO INCLUDE THE
C SEMI-INFINITE REAR GROUND PLANE
       TEMP2=DR-DBLE(FLOAT(IL))+DPI
      TEMP=R2+AZ
```

```
      F1=SQRT(TEMP*TEMP+AY*AY)
      F3=-BI*TEMP/(B1*F1)
      TC=SQRT(1.+AY*AY/(TEMP*TEMP))
      T2=TC*AI
      B1=B1*TC
      B=SQRT((1./B1+1./AI)/(TC*TC*TC))
      G=BI/(T2*T2+B1*B1*B)
      TEMP=SAK*F1
      SF=SIN(TEMP)
      FC=COS(TEMP)
      TEMP=AI*G/SAK/72
C
C       HR AND HI ARE THE REAL AND IMAGINARY PARTS OF THE COMPLEX
C "GAIN" FACTOR OF THE GROUND SURFACE SCATTERING TO THE RECIEVER
C LOCATION
      HR=-TEMP*(SF*FC/(SAK*TB))
      HI=TEMP*(FC*SF/(SAK*TB))
C
C       THIS SUBROUTINE SUMS THE "GAIN" FACTOR FOR EACH STRIP OF
C THE GROUND SURFACE
      CALL SCAT
C
C       THIS SECTION INCLUDES THE EFFECT OF THE DIRECT RADIATION FROM
C THE ANTENNA ELEMENT AT THE RECEIVER
      HR=HR+SQRT2L
      HI=HI+SQRT2L
      TEMP=CELX/(R*P)
      SF=SIN(TEMP2)
      FC=COS(TEMP2)
C
C       CTEMP IS THE COMPLEX GAIN FACTOR INCLUDING ALL RADIATION FROM
C THIS ELEMENT
      CTEMP=CMPLX(-TEMP*SF*HR+HI,TEMP*FC+HR+HI)
C
C       THIS SECTION ACCUMULATES THE FIELDS OF THE VARIOUS FREQUENCIES
      CF81=CF81+CTEMP*CF1(IEL)
      CF82=CF82+CTEMP*CF2(IEL)
      CF83=CF83+CTEMP*CF3(IEL)
      ALPH=SAK*2.*AI*BI/B
      CTEMP=TEMP*.5/LAMBDA*CMPLX(-SF,FC)*
     1CMPLX((1.-COS(ALPH)),-SIN(ALPH))
      CF81=CF81+CTEMP*CF1(IEL)
      CF82=CF82+CTEMP*CF2(IEL)
      CF83=CF83+CTEMP*CF3(IEL)
3     CONTINUE
C
C       AFTER THE FIELDS HAVE BEEN ACCUMULATED FOR ALL THE ELEMENTS
C THE CDI'S ARE CALCUATED
C       ACDR    CDI FOR THE GROUND SURFACE
C       ACDI    CDI FOR 'IDEAL' GROUND PLANE
      ACDR=637.140*REAL((CF83-CF81)/CF81)
      ACDI=637.140*REAL((CF83-CF82)/CF81)
C
```

```
      C       NCRP IS THE COUNT OF THE [illegible]
              NCP=NCP+1
              IF(NCP .NE. 1) GO TO 4
      C
      C       THIS SECTION INITIALIZES THE MAXIMUM AND MINIMUM VALUES
      C OF THE VARIOUS RANGE AND DOMAIN VARIABLES.  THESE ARE
      C USED IN THE PLOTTING PROGRAM TO SCALE THE PLOTS.  AFTER THE
      C [illegible] IS FINISHED THEY WILL BE OUTPUT IN PLACE OF THE
      C INITIAL DUMMY RECORD
              ABDIMACDI
              ADDIMACDR
              TEMPT
              ADIXMACDI
              ADIYMACDI
              ADIFMACDI
              ADRXMACDR
              ADRYMACDR
              ADRFMACDR
              RXFTMPI
              RYFTMPI
              RIFTMPI
              RTFTMPI
              AIFTMACDI
              ARFTMACDR
              RXMAXPI
              RXMINPI
              RYMAXPI
              RYMINPI
              RIMAXPI
              RIMINPI
              RTMAXPI
              RTMINPI
              AIFIMACDI
              AIMAXMACDI
              ARFIMACDR
              ARMAXMACDR
      C
      C       THIS SECTION UPDATES THE MAXIMUM AND MINIMUM VALUES
      4       CONTINUE
              RXLTMPI
              RYLTMPI
              RILTMPI
              RTLTMPI
              AILTMACDI
              ARLTMACDR
              IF(RI .LT. RIMN) RIMNMPI
              IF(RI .GT. RIMX) RIMXMPI
              IF(RT .LT. RTMN) RTMNMPI
              IF(RT .GT. RTMX) RTMXMPI
              IF(RI .GT. RIMX) RIMXMPI
              IF(RI .LT. RIMN) RIMNMPI
              IF(RT .GT. RTMX) RTMXMPI
              IF(RT .LT. RTMN) RTMNMPI
```

```
213                 IF(ACDI .GT. AIMX) AIMX=ACDI
214                 IF(ACDI .LT. AIMN) AIMN=ACDI
215                 IF(ACDR .GT. ARMX) ARMX=ACDR
216                 IF(ACDR .LT. ARMN) ARMN=ACDR
217                 CON=EXP((TO-RT)/TAU)
218           C
219           C       THIS  SECTION SIMULATE THE EFFECT OF THE ELECTICAL AND
220           C MECHANICAL 'INERTIA' OF THE ILS
221           C RECEIVER SYSTEM FOR DYNAMIC SIMULATION
222                 TO=RT
223                 ADDI=CON*(ADDI-ACDI)+ACDI
224                 ADDR=CON*(ADDR-ACDR)+ACDR
225                 IF(ADDI .LT. ADIN) ADIN=ADDI
226                 IF(ADDI .GT. ADIX) ADIX=ADDI
227                 ADIL=ADDI
228                 IF(ADDR .LT  ADRN) ADRN=ADDR
229                 IF(ADDR .G , ADRX) ADRX=ADDR
230                 ADRL=ADDR
231           C
232           C       THIS IS THE OUTPIUT OF THE REAL AND 'IDEAL' , STATIC
233           C AND DYNAMIC CDI'S WWITH THE RECEIVER COORDINATES
234                 WRITE(1,2003) RX,RY,RI,RT,ACDI,ACDR,ADDI,ADDR
235           2003  FORMAT(8F)
236                 GO TO 201
237           C
238           C       THIS IS THE TERMINATION SECTION,  THE INITIAL RECORD ON
239           C THE OUTPUT FILE IS WRITIEN AND THE PROGRAM TERMINATES.
240           200   CALL RELEAS (1)
241                 CALL DEFINE FILE(1,25,I,'STRIP,DAT')
242                 :RITE(1#1) IPTDAT
243                 CALL RELEAS (1)
244                 CALL EXIT
245                 STOP
246                 END
```

CONSTANTS

0	2036220077325	1	150042055061	2	000000000001	3	516512244640	4	000000000000
5	00000000002	6	436451642100	7	000000000000	10	000000000000	11	212654443656
12	000000000031	13	516512244640	14	272[illegible]152100	15	000000000000		

COMMON

NRP	/PLXT	/+0	RXMN	/PLXT	/+1	RXMX	/PLXT	/+2	RXFT	/PLXT	/+3	RXLT	/PLXT	/+4
RYMN	/PLXT	/+5	RYMX	/PLXT	/+6	RYFT	/PLXT	/+7	RYLT	/PLXT	/+10	RZMN	/PLXT	/+11
RZMX	/PLXT	/+12	RZFT	/PLXT	/+13	RZLT	/PLXT	/+14	RTMN	/PLXT	/+15	RTMX	/PLXT	/+16
RTFT	/PLXT	/+17	RTLT	/PLXT	/+20	AIMN	/PLXT	/+21	AIMX	/PLXT	/+22	AIFT	/PLXT	/+23
AILT	/PLXT	/+24	ARMN	/PLXT	/+25	ARMX	/PLXT	/+26	ARFT	/PLXT	/+27	ARLT	/PLXT	/+30
ADIN	/PLXT	/+31	ADIX	/PLXT	/+32	ADIF	/PLXT	/+33	ADIL	/PLXT	/+34	ADRN	/PLXT	/+35
ADRX	/PLXT	/+36	ADRF	/PLXT	/+37	ADRL	/PLXT	/+40	RX	/REC	/+0	RY	/REC	/+1
RZ	/REC	/+2	RT	/REC	/+3	NSIZE	/REC	/+4	K	/GROUND	/+0	X1	/GROL	/+1
Z1	/GROUND	/+25	X2	/GROUND	/+51	Z2	/GROUND	/+76	IEL	/GROUND	/+123	AX	/ANT	/+0
AY	/ANT	/+1	AZ	/ANT	/+2	LAMBDA	/ANT	/+3	DAK	/ANT	/+4	DPI	/ANT	/+6

HR /VAL /+0 HI /VAL /+1 IPTDAT /PLXT /+0

SUBPROGRAMS

FORSE,	JBFF	OFILE	BINAR,	IF	ALPHD,	ALPHI,	IFILE	RELEAS	SQRT	DBLE	DFD.2	SNGL	IMPUT	DSQRT
DFN.2	DFN.4	DFA.2	DFN.6	DFNN.2	IOINT	FLOAT	DFN.0	DFS.0	SIN	COS	DFD.4	DFA.4	DFS.4	SCAT
CMPLX	CFN.2	CFN.0	REAL	CFD.2	EXP	FLOUT,	FLIRT,	DEFINE	RECVD,	RANAC,	EXIT			

SCALARS

DPI	6	TAU	1320	NRP	0	K	0	ILBL	1321			
LAMBDA	3	NFL	1322	I	1323	SQRT2L	1324	TEMP2	1325			
DAK	4	SAK	1326	CFR1	1327	CFR2	1331	CFR3	1333			
CFS1	1335	CFS2	1337	CFS3	1341	R2	1343	RX	0			
RZ	2	IEL	123	AX	0	AY	1	AZ	2			
DELX	1344	DELY	1346	RY	1	DELZ	1350	DR	1352			
R	1354	IL	1355	TEMP	1356	F1	1357	F2	1360			
TC	1361	TD	1362	R1	1363	S	1364	G	1365			
SF	1366	FC	1367	HR	0	HI	1	CTEMP	1370			
ALPH	1372	ACDR	1373	ACDI	1374	ADDI	1375	ADDR	1376			
TQ	1377	RT	3	ADIX	32	ADIN	31	ADIF	33			
ADRX	36	ADRN	35	ADRF	37	RXFT	3	RYFT	7			
RZFT	13	RTFT	17	AIFT	23	ARFT	27	RXMN	1			
RXMX	2	RYMN	5	RYMX	6	RZMN	11	RZMX	12			
RTMN	15	RTMX	16	AIMX	22	AIMN	21	ARMX	26			
ARMN	25	RXLT	4	RYLT	10	RZLT	14	RTLT	20			
AILT	24	ARLT	30	CON	1400	ADIL	34	ADRL	40			
NSIZE	4											

ARRAYS

ILABL	1402	IPTDAT	0	X	1412	Y	1436	Z	1462
CF1	1506	CF2	1556	CF3	1626	X1	1	Z1	25
X2	51	Z2	76						

G	113	117										
GROUND	15											
HI	17	123	133	139								
HR	17	122	131	139								
I	57	241										
IEL	15	88	92	93	94	142	143	144	148	149	150	
IF	34											
IFILE	42	54										
IL	101	105										
ILABL	1	34	36	43	41	55	56					
ILEL	52	54										
INPUT	68											
IPTDAT	2	8	28	242								
K	15	45										
LAMBDA	14	16	57	59	60	61	146					
NEL	57	88										
NRP	3	8	39	161	162							
NSIZE	13											
OFILE	24											
PLXT	3											
R	99	133	145									
R1	111	113										
R2	84	108	108	111	112							
REAL	157	158										
REC	13											
RELEAL	44	58	240	243								
RT	13	171	181	190	191	202	211	212	217	222	224	
RTFT	3	181										
RTLT	3	202										
RTMN	3	190	212									
RTMX	3	191	211									
RX	13	84	95	108	113	170	184	185	199	203	206	230
RXFT	3	178										
RXLT	3	199										
RXMN	3	184	205									
RXMX	3	185	206									
RY	13	96	179	186	187	200	207	208	234			
RYFT	3	179										
RYLT	3	200										
RYMN	3	186	207									
RYMX	3	187	208									
RZ	13	84	97	145	190	188	189	201	209	210	334	
RZFT	3	180										
RZLT	3	201										
RZMN	3	188	210									
RZMX	3	189	209									
S	112	113										
SAK	62	114	145									
SCAT	127											
SY	115	122	123	134	139	146						
SIN	115	134	146									
SNGL	62	99										
SQRT	59	84	107	109	112							

SQRT2L	59	131	132										
TO	271	217	222										
TAU	34	217											
TC	109	110	111	112									
TD	110	113	122	123									
TEMP	106	107	108	109	114	115	116	117	122	123	133	139	146
TEMP2	60	105	134	135									
VAL	17												
X	10	97	92										
X1	15	45											
X2	15	45											
Y	10	97	93										
Z	10	97	94										
Z1	15	45											
Z2	15	45											

3P	88	191					
4P	162	198					
200P	68	240					
201P	68	236					
1000P	35	36	43	44	55	56	
2000P	92	93					
2001P	90	91					
2003P	234	235					

```
      1          C
      2          C       THIS SUBROUTINE OPENS THE FLIGHT PATH FILE AND INPUTS THE
      3          C FLIGHT PATH PLOT LABEL AND THE INERTIAL TIME CONSTANT
      4          C
      5          C       THIS SUBROUTINE INPUTS THE RECEIVER LOCATION
      6          C COORDINATES OF THE NEXT POINT ON THE FLIGHT PATH.  IF THERE
      7          C ARE NO MORE POINTS THE SUBROUTINE EXITS TO THE
      8          C END RETURN POINT
      9                SUBROUTINE IF(ILABL,TAU)
     10                DIMENSION ILABL(8)
     11                COMMON/REC/ DUM(4),NSIZ
     12                CALL JOVSET(1,'PATH.DAT',NS)
     13                WRITE(5,1000) NS
     14           1000 FORMAT(I5,' RECORDS IN PATH.DAT',/)
     15                NSIZE=(NS-8)/4
     16                CALL JOVMI(1,ILABL,8,0)
     17                CALL JOVMI(1,TAU,1,0)
     18                RETURN
     19                END
```

CONSTANTS

0	000000000001	1	502032446134	2	422032420106	3	000000000000	4	000000000010

GLOBAL DUMMIES

ILABL	66	TAU	67

COMMON

DUM	/REC	/+0	NSIZE	/REC	/+4

SUBPROGRAMS

JOVSET INTO. INTI. JOVMI

SCALARS

IF	70	NS	71	NSIZE	4	TAU	67

ARRAYS

ILABL	66	DUM	0

DUM	11		
IF	9		
ILABL	9	10	16
JOVSET	12		
JOV#I	16	17	
%S	12	13	15
%SIZE	11	15	
REC	11		
TAU	9	17	

1030P	13	14

```
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    1               SUBROUTINE INPUT(6)
    2               COMMON /REC/ RX(4),NSIZE
    3               IF(NSIZE .LE. 0) RETURN 1
    4               CALL JOVNI(1,RX,4,0)
    5               NSIZE=NSIZE-1
    6               RETURN
    7               END

      CONSTANTS

      0       000000000001    1       000000000004    2       000000000000

      COMMON

      RX      /REC    /+0     NSIZE   /REC    /+4

      SUBPROGRAMS

      JOVNI

      SCALARS

      INPUT   36              NSIZE   4

      ARRAYS

      RX      0
```

INPUT	1		
JOYWI	4		
MAIZE	2	3	5
REC	2		
RX	2	4	

```
      C
      C       THIS SUBROUTINE SUMS THE EFFECTS OF THE STRIPS THAT MAKE
      C UP THE GROUNDSURFACE.  THERE ARE 'K' STRIPS DESCRIBED IN COMMON
      C GROUND AS FOLLOWS:
      C       X1(I)   THE X-COORDINATE OF THE LEADING EDGE OF THE I'TH STRIP
      C       Z1(I)   THE Z-COORDINATE OF THE LEADING EDGE OF THE I'TH STRIP
      C       X2(I)   THE X-COORDINATE OF THE ENDING EDGE OF THE I'TH STRIP
      C       Z2(I)   THE Z-COORDINATE OF THE ENDING EDGE OF THE I'TH STRIP
            SUBROUTINE SCAT
            COMMON /REC/ RX,RY,RZ
            COMMON /ANT/AX,AY,AZ
            COMMON /GROUND/ K,X1(20),Z1(20),X2(0/20),Z2(0/20),IEL
            COMMON /SEG/ XX1,ZZ1,XX2,ZZ2,N
      C
      C       THESE ARE INITIAL VALUES FOR THE PARAMETERS USED IN SHADOWING
            SI =1.
            PMAX=1.
      C
      C       THIS IS THE LOOP OVER THE STRIPS
            DO 1 I=1,K
      C
      C       THESE ARE THE VALUES TO BE USED IN THE STRIP
      C INTEGRATION SUBROUTINE
      C       XX1     LEADING X-COORDINATE
      C       ZZ1     LEADING Z-COORDINATE
      C       XX2     TRAILING X-COORDINATE
      C       ZZ2     TRAILING Z-COORDINATE
            XX1=X1(I)
            ZZ1=Z1(I)
            XX2=X2(I)
            ZZ2=Z2(I)
      C
      C       THIS IS A TEST TO SEE IF THE SUMMATION OVER THE GROUND
      C STRIPS HAS REACHED THE RECEIVER LOCATION.  IF IT HAS THE SUMMATION
      C IS STOPPED.  THIS IS TO GIVE THE EFFECT OF FOWARD LOOKING RECEIVER
      C ANTENNA PATTERN.
            IF( XX1 .GT. RX) GO TO 6
      C
      C       IF THE RECIEVER IS LOCATED OVER THE MIDDLE PORTION OF A STRIP
      C THE STRIP WILL BE INTEGRATE ONLY UP TO THE VALUE OF THE
      C RECEIVER X-COORDINATE
            IF(XX2 .LE. RX) GO TO 5
            ZZ2=ZZ1+(RX-XX1)*(ZZ2-ZZ1)/(XX2-XX1)
            XX2=RX
      5     CONTINUE
      C
      C       THIS SECTION DOES THE SHADOWING.  IF PART OR ALL OF THE STRIP
      C IS IN THE SHADOW OF A PREVIOUS STRIP, THIS STRIP WILL BE ELIMINATED
      C OR MASKED TO GIVE THE EFFECT OF SHADOWING.
            DELX=XX2-AX
            IF(DELX .LE. 0.) GO TO 3
            SMIS=(AZ-ZZ2)/DELX
            IF(SLOPE .LT. 0.) GO TO 3
```

```
                IF(PHIE .GE. SLOPE) GO TO 1
                PHIB=(AZ-ZZ1)/(XX1-AX)
                IF( PHIB .LE. SLOPE) GO TO 3
                IF( XX1 .EQ. XX2) GO TO 4
                A=(ZZ2-ZZ1)/(XX2-XX1)
                B=ZZ1-A*(XX1-AX)
                XX1=(AZ-B)/(A-SLOPE)+AX
          4     ZZ1=-SLOPE*(XX1-AX)+AZ
          C
          C       THIS SUBROUTINE WILL INTEGRATE OVER THE STRIP THE
          C COMPLEX 'GAIN' EFFECT OF THIS STRIP WILL BE ADDED TO HR AND HI
          C IN COMMON 'VALL'
          3     CALL SUM
                SLOPE=PHIE
          1     CONTINUE
          6     RETURN
                END
```

CONSTANTS

```
0       201400000000
```

COMMON

```
RX      /REC   /+0      RY      /REC   /+1      RZ      /REC   /+2      AX      /ANT   /+0      AY      /ANT   /+1
AZ      /ANT   /+2      K       /GROUND/+0      X1      /GROUND/+1      Z1      /GROUND/+25     X2      /GROUND/+51
Z2      /GROUND/+76     IEL     /GROUND/+123    XX1     /SEG   /+0      XC1     /SEG   /+1      XX2     /SEG   /+2
ZZ2     /SEG   /+3      N       /SEG   /+4
```

SUBPROGRAMS

```
SUM
```

SCALARS

```
SCAT    143             SLOPE   144             PHIE    145             I       146             K       0
XX1     0               ZZ1     1               XX2     2               ZZ2     3               RX      0
DELX    147             AX      0               AZ      2               PHIB    150             A       151
B       152             RY      1               RZ      2               AY      1               IEL     133
N       4
```

ARRAYS

```
X1      1               Z1      25              X2      51              Z2      76
```

A	58	59	60							
ANT	11									
A1	11	58	55	59	60	61				
AT	11									
A2	11	52	55	60	61					
B	59	60								
BCLK	50	51	52							
CARRIED	12									
C	20	28	29	30	31					
CKL	12									
E	12	28								
E	13									
FHIB	55	56								
FHIC	17	52	54	67						
HDC	10									
HI	10	37	42	43	44					
HT	10									
HI	10									
HCAT	9									
HDS	13									
HL/DPC	14	53	56	56	66	61	67			
HDH	66									
I1	12	28								
I2	12	30								
II1	13	28	37	43	55	57	58	59	60	61
II2	13	30	42	45	44	38	37	38		
I1	12	29								
I2	12	31								
II1	13	29	43	55	58	59	61			
II2	13	31	43	52	58					

19	28	54	68	
39	51	53	56	58
49	57	61		
57	42	45		
69	37	69		

```
      1          C
      2          C       THIS SUBROUTINE INTEGRATES OVER THE SURFACE STRIP DEFINED
      3          C BY X1,Z1,X2,Z2 IN COMMON 'SEC', TO GIVE THE FIELD EFFECT
      4          C OF THEANTENNA ELEMENT IN COMMON 'ANT' AT RECIEVER DEFINED
      5          C IN COMMON 'REC'.  THE VARIABLES ARE AS FOLLOWS:
      6          C       AX      ANTENNA X-COORDINATE
      7          C       AY      ANTENNA Y-COORDINATE
      8          C       AZ      ANTENNA Z-COORDINATE
      9          C       LAMBDA  WAVELENGTH OF CARRIER
     10          C       AK      TWO*PI/LAMBDA
     11          C       DPI     TWO*PI (DOUBLE PRECISION)
     12          C       RX      RECEIVER X-COORDINATE
     13          C       RY      RECEIVER Y-COORDINATE
     14          C       RZ      RECEIVER Z-COORDINATE
     15          C       HR      REL PART OF 'GAIN' FACTOR
     16          C       HI      IMAGINARY PART OF 'GAIN' FACTOR
     17          C       X1      LEADING EDGE OF STRIP'S X-COORDINATE
     18          C       Z1      LEADING X-COORDINATE
     19          C       X2      TRAILING EDGE X-COORDINATE
     20          C       Z2      TRAILING Z-COORDINATE
     21          C THE INTEGRATION IS PERFORMED BY A MODIFIED TRAPIZOID RULE.
     22          C THE SPACING BETWEEN POINTS ALONG THE VARIABLE OF INTEGRATION
     23          C IS VARIED BY THE RATE OF CHANGE OF THE INTEGRAND.
     24                SUBROUTINE SUB
     25                COMMON /SEC/ X1,Z1,X2,Z2,M
     26                DOUBLE PRECISION A1,A2,B1,B2,XL,AY2
     27                REAL  JR,JI,JDR,JDI,JNR,JNI
     28                REAL LAMBDA
     29                 DOUBLE PRECISION AK,DPI,DR
     30                COMMON /ANT/AX,AY,AZ,LAMBDA,AK,DPI
     31                COMMON /REC/RX,RY,RZ
     32                COMMON /VAL/HR,HI
     33                REAL L3,L10
     34          C
     35          C       THIS IS THE INITIALIZATION SECTION
     36                AY2=DBLE(AY)*DBLE(AY)
     37                AKK=SNGL(AK)
     38                SE=Z2-Z1
     39                CE=X2-X1
     40          C
     41          C       XMAX IS THE LENGTH ALONG THE SURFACE OF THE STRIP
     42                XMAX=SQRT(SE*SE+CE*CE)
     43          C
     44          C       THESE ARE THE SIN AND COS OF THE ANGLE THE STRIP MAKES WITH
     45          C A HORIZONTAL PLANE
     46                SE=SE/XMAX
     47                CE=CE/XMAX
     48                JR=0.
     49                JI=0.
     50          C
     51          C       XL IS THE VARIABLE OF INTEGRATION.  IT IS THE DISTANCE
     52          C ALONG THE SURFACE OF THE STRIP STARTING FROM THE LEADING EDGE
     53                XL=0.
```

```
      NI=1
      IT=0
C
C       THESE ARE THE LOWER AND UPPER BOUNDS FOR THE SPACING BETWEEN
C POINTS ALONG THE VARIABLE OF INTEGRATION
      L1= LAMBDA/24.
      L10=20.*LAMBDA
      A1=RI-ZI
      A2=RI-ZI
      B1=ZI
      B2=ZI-AI
      A=A1
      TEMP=A2
       A= SQRT(A*A+TEMP*TEMP)
      B=B1
      TEMP=B2
      B= SQRT(B*B+TEMP*TEMP)
      TEMP=A+B
      DR=DSQRT(DBLE(TEMP)*DBLE(TEMP)+DBLE(AY*AY))
      C=DR
      DR=DR*AR
      I=DR/DPI
      F=DR-DBLE(FLOAT(I))*DPI
      C=C/TEMP
      D=C*B
      E=C*A
       S=SQRT((1./A+1./B)/C/C/C)
      G=A1/7/D/E/E/E
      TEMP=G/(AKK*B)
      CF=COS(F)
      SF=SIN(F)
      JCR=C*CF*TEMP*SF
      JCI=C*SF*TEMP*CF
      AP=(-A1*CK+A2*SK)/A
      BP=(B1*CK+B2*SK)/L
C
C       FP IS THE DERIVATIVE OF THE PHASE FUNCTION
C OF THE INTEGRAND
      FP=ABS((AP+BP)/C)
C
C       DL IS DELTA XL
      DL=L1/FP
      IF(DL .GT. L10) DL=L10
      IF(DL .LT. L1) DL=L1
      XL=XL+DL
C
C       THIS IS THE LOOP OVER THE SURFACE OF THE STRIP.  XL IS
C INCREMENTED BY DL (OF VARIABLE SIZE) UNTIL THE END OF THE STRIP
C IS REACHED (XMAX)
1     CONTINUE
C
C       THIS SECTION CALCULATE VARIOUS TERMS USED IN EVALUATING THE
C INTEGRAND,  THE AMPLITUDE AND PHASE FUNCTION
```

```
C ARE EVALUTATED SEPARATELLY.  THE DERIVATIVE OF THE PHASE FUNCTION
C IS EVALUATED TO DETERMUINE THE SIZE FOR DELTA X
      DLSE=DL*SE
      DLCE=DL*CE
      A1=A1+DLCE
      A2=A2+DLSE
      B1=B1+DLCE
      B2=B2+DLSE
      A=A1
       TEMP=A2
      A= SQRT(A*A+TEMP*TEMP)
      B=B1
      TEMP=B2
      B= SQRT(B*B+TEMP*TEMP)
      TEMP=A*B
      DR=DSQRT(DBLE(TEMP)*DBLE(TEMP)+DBLE(AY*AY))
      C=SNGL(DR)/TEMP
      DR=DR*AK
      I=DR/DPI
C
C       THIS IS THE PHASEE ANGLE "MODULO TWO PI"
      F=DR-DBLE(FLOAT(I))*DPI
      D=C*B
      R=C*A
      S=SQRT((1./A+1./B)/C)/C
      G=A1/(D*D*R*R*S)
C
C       THIS IS THE AMPLITUDE FUNCTION
      TEMP=G/(AKK*D)
      CF=COS(F)
      SF=SIN(F)
C
C       THIS IS THE REAL PART OF THE INTEGRAND FOR THE
C INTEGRATION VARIABLE VALUE OF XL
      JNR=G*CF-TEMP*SF
C
C       THIS IS THE IMAGINARY PART
      JNI=G*SF+TEMP*CF
      TEMP=DL
C
C       THESE ARE THE REAL AN IMAGINARY PARTS OF THE THE SUMMATION
C OF THE TRAPIZOIDS MAKING U.  THE APPROXIMATION TO THE INTEGRAL
      JR=JR+(JOR+JNR)*TEMP
      JI=JI+(JOI+JNI)*TEMP
       IF(IT .NE. 0) GO TO 2
      JOR=JNR
      JOI=JNI
      AP=(-A1*CE-A2*SE)/A
       BP=(B1*CE+B2*SE)/B
C
C       FP IS THE DERIVATIVE OF THE PHASE FUNCTION
      FP=ABS((AP+BP)/C)
C
```

```
160           C       DL IS DELTA X AND IS LIMITED BY THE BOUNDS L3,L10
161                 DL=L3/FP
162                 IF(DL .GT. L10) DL=L10
163                 IF(DL .LT. L3) DL=L3
164                 NX=NX+1
165           C
166           C       THE VARIABLE OF INTGRATION IS INCREMENTED AND IF THE END OF THE
167           C STRIP IS REACHED THE LAST TRAPIZOID IS ADDED
168                 XL=XL+DL
169                 IF( XL .LT. XMAX) GO TO 1
170                 DL=XMAX-DL=XL
171                 XL=XMAX
172                 IT=1
173                 GO TO 1
174           C
175           C       THIS SECTION ADDS THE FIELD EFFECT FROM THE STRIP TO THE
176           C TOTAL FIELD SUM AND TEH SUBROUTINE TERMINATES
177           2     CONTINUE
178                 N=NX
179                 TEMP=((Z1-AZ)*CE-X1*SE)/2.
180                 HR=HR+JR*TEMP
181                 HI=HI+JI*TEMP
182                 RETURN
183                 END
```

CONSTANTS

0 205600000000

COMMON

X1	/SEG	/+0	Z1	/SEG	/+1	X2	/SEG	/+2	Z2	/SEG	/+3	N	/SEG	/+4
AX	/ANT	/+0	AY	/ANT	/+1	AZ	/ANT	/+2	LAMBDA	/ANT	/+3	AK	/ANT	/+4
DPI	/ANT	/+5	RX	/REC	/+0	RY	/REC	/+1	RZ	/REC	/+2	HR	/VAL	/+0
HI	/VAL	/+1												

SUBPROGRAMS

DBLE	DFX,0	SNGL	SQRT	DSQRT	DFA,0	DFMM,2	DFD,2	IDINT	FLOAT	DFS,0	DFD,6	COS	SIN	DFM,4
DFM,6	DFA,4	DFD,4	ABS	DFAM,2	DFS,2									

SCALARS

SUM	1084	A/2	1085	AY	1	AKK	1067	AK	6
SE	1070	Z2	3	Z1	1	CE	1071	X2	2
X1	0	XMAX	1072	JR	1073	JI	1074	XL	1075
NX	1077	IT	1100	L3	1101	LAMBDA	3	L10	1102
A1	1103	RX	0	A2	1105	RZ	2	B1	1107
B2	1111	AZ	2	A	1113	TEMP	1114	B	1115
DR	1116	C	1120	I	1121	DPI	6	F	1122
D	1123	R	1124	S	1125	G	1126	CF	1127
SF	1130	JOR	1131	JOI	1132	AP	1133	BP	1134
FP	1135	DL	1136	DLSE	1137	DICE	1140	JNR	1141

JMI 1142 N 4 HR 0 MI 1 AX 0
RY 1

APPENDIX B

FMAKE LISTING

```
FMAKE.F4        F40     V26(14) 21-JUL-74       17:52   PAGE 1

      1                 DIMENSION IDUM(2)
      2                 DATA IDUM(2)/'.DAT'/
      3                 COMMON XX,YY,ZZ,TT
      4                 DIMENSION ILABL(8)
      5                 DIMENSION X(20),Y(20),Z(20)
      6                 IMPLICIT COMPLEX (C)
      7                 DIMENSION C1(20),C2(20),C3(20)
      8                 COMMON /GROUND/ K,X1(20),Z1(20),X2(0/20),Z2(0/20).
      9           C
     10           C    THIS SECTION ACCEPTS THE INPUT OF THE SWITCH (ONE
     11           C DETERMINE WHAT KIND OF FILE TO GENERATE.
     12           C       <BLANK> TO END THE PROGRAM
     13           C       Y       TO SET ANTENNA OFFSET AND XMISSION WAVELE
     14           C       G       FOR GROUND DESCRIPTION
     15           C       P       FOR FLIGHT PATH
     16           C       A       FOR ANTENNA DESCRIPTION
     17           2     WRITE(5,1013)
     18                 READ(5,1009) NAME
     19                 IF(NAME .EQ.' ') GO TO 3
     20                 IF(NAME .EQ. 'Y') GO TO 20
     21                 IF(NAME .EQ. 'G') GO TO 21
     22                 IF(NAME .EQ. 'P') GO TO 22
     23                 IF(NAME .EQ. 'A') GO TO 23
     24                 WRITE(5,1012)
     25                 GO TO 2
     26           C
     27           C       THIS IS THE INPUT FOR THE ANTENNA OFFSET AND FOR THE
     28           C TRANSMISSION WAVELENGTH, BOTH ARE IN FEET AND ARE FLOATING POINT.
     29           20    WRITE(5,1011)
     30                 READ(5,101) YO,RL
     31                 GO TO 2
     32           C
     33           C       THIS SECTION IS FOR  GROUND DESCRIPTION
     34           21    WRITE(5,1014)
     35           C
     36           C       THIS IS TO INPUT THE FILE NAME FOR GROUND DESCRIPTION
     37                 READ(5,105) IDUM(1)
     38                 WRITE(5,104)
     39           C
     40           C       THIS IS TO INPUT THE PLOT LABEL FOR GROUND DESCRIPTION
     41                 READ(5,105) ILABL
     42                 WRITE(5,106)
     43           C
     44           C       THIS IS THE INPUT FOR THE GROUND STRIP EDGE COORINATES
     45           C       R       DELTA X-COORDINATE FOR CARTESIAN AND
     46           C               RANGE FOR POLAR COORDINATES
     47           C       ZZ      DELTA Y-COORDINATE FOR CARTESIAN AND
     48           C               USUALLY ZERO FOR POLAR COORDINATES
     49           C       THETA   ZERO FOR CARTESIAN COORDINATES AND
     50           C               THE ELEVAION ANGLE FOR POLAR
     51           C       THIS IS THE INPUT FOR THE STARTING EDGE OF THE FIRST STRIP
     52                 READ(5,101,END=2) R,ZZ,THETA
     53                 X2(0)=R*COSD(THETA)-ZZ*SIND(THETA)
```

```
      Z2(0)=R*SIND(THETA)+ZZ*COSD(THETA)
      K=0
      WRITE(5,102)
C
C       THIS IS THE INPUT LOOP FOR THE REST OF THE STRIP EDGES. THE
C EDGES ARE THE TRAILING EDGE OF THE PREVIOUS STRIP AND THE
C LEADING EDGE OF THE NEXT.  THE LOOP WILL CONTINUE TO A MAXIMUM OF
C TWENTY STRIPS OR UNTIL BOTH 'R' AND 'ZZ' ARE ZERO.
11    READ(5,101,END=2) R,ZZ,THETA
      IF(R.NE.0.) GO TO 5
      IF(ZZ.NE.0.) GO TO 5
      IF(K.EQ.0) GO TO 2
      GO TO 4
5     K=K+1
      X1(K)=X2(K-1)
      Z1(K)=Z2(K-1)
      X2(K)=X2(K-1)+R*COSD(THETA)-ZZ*SIND(THETA)
      Z2(K)=Z2(K-1)+R*SIND(THETA)+ZZ*COSD(THETA)
      IF(K.LT.20) GO TO 6
      WRITE(5,103)
      GO TO 4
6     WRITE(5,102)
      GO TO 11
C
C       THIS OPENS A FILE FOR THE GROUND DESCRIPTION, OUTPUTS IT
C IN BINARY AND CLOSES THE FILE. FLOW THEN RETURNS TO THE SWITCH POINT.
4     CALL OFILE(20,IDUM(1))
      WRITE(20,105) ILABL
      WRITE(20) K,X1,Z1,X2,Z2
      CALL RELEAS(20)
      GO TO 2
C
C       THIS IS THE SECTION TO GENERATE A FLIGHT PATH FILE.
22    WRITE(5,1015)
C
C       THIS INPUTS THE FLIGT PATH FILE NAME
      READ(5,105) IDUM(1)
C
C       THIS IS TO CREATE THE FILE IF ONE DOES NOT ALREADY EXIST.
C THIS IS NECESSARY AS JOVRAX DOES NOT CREATE FILES.
      CALL OFILE (20,IDUM(1))
      CALL RELEAS(20)
C
C       THIS IS TO OPN THE FILE FOR JOVVRAX
      CALL JOVSET(1,IDUM(1),NSIZE)
      WRITE(5,1003)
C
C       THIS IS TO INPUT THE FLIGHT PATH PLOT LABEL AND OUTPUT IT TO
C THE FILE

      READ(5,105) ILABL
      CALL JOVNO(1,ILABL,8,0)
      WRITE(5,1008)
```

```
C
C       THIS SWITCH IS TO SELECT EITHER STRIGHT LINE FLIGHT OR
C HYPERBOLIC.  'G' INPUT WILL SELECT HYPERBOLIC ANYTHING ELSE WILL
C GIVE STRIGHT LINE.
      READ(5,1009) I
      IF(I .NE. 'G') GO TO 12
C
C       THIS IS THE HYPERBOLIC FLIGT SECTION
      WRITE(5,1010)
C
C       THIS IS THE INPUT TO DESCRIBE THE FLIGHT
C       XO      STARTING X-COORDINATE
C       XF      ENDING X-COORDINATE
C       H       HEIGHT OF MAIN ELEMENT USED TO DETRMINE GLIDE ANGLE
C               AND HEIGHT ABOVE GROUND OF ZERO CDI SURFACE AT CLOSEST
C               APPROACH
      READ(5,101) XO,XF,H
      WRITE(5,1006)
C
C       THIS INPUT IS FOR THE FLIGHT PATH QUANTIZATION PARAMETERS
C       NK      IS THE NUMBER OF POINTS ALONG THE FLIGHT PATH
C       V       IS THE VELOCITY (FT./SEC.) OF THE AIRCRAFT
C       TAU     IS THE TIME CONSTANT (SEC.) FOR THE DYNAMIC CDI
      READ(5,1007) NK,V,TAU
      IF(NK .LE. 0) GO TO 22
      CALL JOVWO(1,TAU,1,0)
C
C       THIS LOOP GENERATES THE COORINATES OF THE POINTS ALONG THE
C HYPERBOLA AND OUTPUTS THEM TO THE FLIGHT PATH FILE
      A1=RL+RL+.25-H+H-Y0+Y0
      A2=1./(1.-4.+H+H/RL/RL)
      DX=(XF-XO)/FLOAT(NK-1)
      XX=XO
      YY=0.
      ZZ=0.
      XOL=XX
      ZOL=SQRT((A1-XX+XX)+A2)
      DO 13 I=1,NK
      ZZ=SQRT((A1-XX+XX)+A2)
      TEMP=XX-XOL
      TEMP2=ZZ-ZOL
      ZZ=ZZ-SQRT(TEMP+TEMP+TEMP2+TEMP2)/V
      CALL JOVWO(1,XX,4,0)
      XOL=XX
      ZOL=ZZ
      XX=XX+DX
13    CONTINUE
      GO TO 14
C
C       THIS SECTION IS FOR STRIGHT LINE FLIGHT
12    CONTINUE
      WRITE(5,1004)
C
```

```
C       THESE INPUTS ARE TO DESCRIBE THE FLIGHT PATH
C       XX      STARTING X-COORDINATE (FEET)
C       YY      STARTING Y-COORDINATE (FEET)
C       ZZ      STARTING Z-COORDINATE (FEET)
C       XF      ENDING X-COORDINATE (FEET)
C       YF      ENDING Y-COORDINATE (FEET)
C       ZF      ENDING Z-COORDINATE
C       NK      NUMBER OF POINTS ALONG THE FLIGHT PATH
C       V       VELOCITY OF AIRCRAFT (FEET/SEC.)
C       TAU     TIME CONSTANT FOR DYNAMIC CDI (SE)
      READ(5,101) XX,YY,ZZ
      WRITE(5,1005)
      READ(5,101) XF,YF,ZF
      WRITE(5,1006)
      READ(5,1007) NK,V,TAU
      IF( NK .LE. 0) GO TO 22
      CALL JOYWO(1,TAU,1.0)
      FN=NK-1
      DX=(XF-XX)/FN
      DY=(YF-YY)/FN
      DZ=(ZF-ZZ)/FN
      DT=SQRT(DX*DX+DY*DY+DZ*DZ)/V
      TT=0.
C
C       LOOP TO GENERATE X-,Y-, AND Z-COORDINATES AND OUTPUT THEM
C TO THE FLIGHT PATH FILE
      DO 1 I=1,NK
      CALL JOYWO(1,XX,4,0)
      XX=XX+DX
      YY=YY+DY
      ZZ=ZZ+DZ
1     TT=TT+DT
C
C       THIS CLOSES THE FLIGHT PATH FILE AND RETURNS TO SWITCH POINT
14    CALL JOYREL(1)
      GO TO 2
C
C       THIS SECTION IS TO GENERATE ANTENNA DESCRIPTION FILE
23    N=0
      WRITE(5,107)
C
C       INPUT FOR ANTENNA FILE NAME
      READ(5,2000) ILBL
      WRITE(5,108)
C
C       INPUT FOR ANTENNA PLOT LABEL
      READ(5,103) ILABL
      N=1
C
C       THIS IS THE INPUT FOR ELEMENT DESCRIPTION
C       X(I)    X-COORDINATE OF I'TH ELEMENT (FEET)
C       Z(I)    Z-COORDINATE OF I'TH ELEMENT (FEET)
C       C1(I)   COMPLEX AMPLITUDE OF CARRIER COMPONENT OF I'TH ELEMENT
```

```
C       C2(I)   COMPLEX AMPLITUDE OF 150 MZ SIDEBAND OF I'TH ELEMENT
C       C3(I)   COMPLEX AMPLITUDE OF 90 MZ SIDEBAND OF I'TH ELEMENT
C THE PROGRAM WILL LOOP THRU 10 FOR ADDITIONAL ELEMENTS UNTIL A
C       ZERO IS ENCOUNTERED FOR Z(N)
      WRITE(5,1017)
10    READ(5,2001) X(N),Z(N),C1(N),C2(N),C3(N)
      IF( Z(N) .EQ. 0) GO TO 9
C
C       THIS SECTION DETERMINES THE Y OFFSET OF EACH ELEMENT.  THIS
C IS NOMINALLY YO BUT THERE IS A SMALL CHANGE (LESS THEN ONE WAVELENGTH)
C FOR NEAR FIELD CORRECTION PURPOSES
      S=SIGN(1.,Z(N)-Z(1))
      IF(N .NE. 1) GO TO 15
      Y(1)=YO
      F=SQRT(YO*YO+Z(1)*Z(1))
      GO TO 16
15    XO=YO-SQRT(F*F-Z(N)*Z(N))
      IF(XO*S .LT. 0.) GO TO 17
19    XP=YO-SQRT((F+RL)*(F+RL)-Z(N)*Z(N))
      IF(XP*S .LT. 0.) GO TO 18
      F=F+RL*S
      X0=XP
      GO TO 19
17    F=F+RL*S
      GO TO 15
18    Y(N)=YO-XO
16    CONTINUE
      N=N+1
      GO TO 10
C
C       THIS SECTION OUTPUTS THE ANTENNA DESCRIPTION TO THE FILE
C AND ON THE LINE PRINTER, CLOSES THE FILE AND RETURNS TO THE SWITCH
C POINT
9     NEL=N-1
      CALL OFILE(20,ILBL)
      WRITE(30,105) ILABL
      WRITE(20) RL,NEL,(X(I),Y(I),Z(I),C1(I),C2(I),C3(I),I=1,NEL)
      WRITE(3,1016) ILABL
      WRITE(3,2001) (X(I),Y(I),Z(I),C1(I),C2(I),C3(I),I=1,NEL)
      CALL RELEAS(20)
      GO TO 2
C
C       THIS IS THE PROGRAM TERMINATION POINT
3     CALL EXIT
      STOP
1012  FORMAT(' UNKNOWN SWITCH.')
1013  FORMAT(' INPUT SWITCH:',$)
1014  FORMAT(' INPUT GROUND FILE NAME:',$)
1015  FORMAT(' INPUT FLIGHT PATH FILE NAME:',$)
1017  FORMAT(' INPUT ELEMENT VALUES..',/)
1016  FORMAT(2X,8A5)
104   FORMAT(' INPUT GROUND LABEL ./)
105   FORMAT(8A5)
```

```
246                 1WAT(' INPUT GROUND SEGMENTS,  STARTING FROM ANTENNA,',/,
247                 2IVE CONSECUTIVELY EITHER X AND Z INCREMENTS, OR THE',/,
248                 3LENGTH AND ANGLE FROM HORIZONTAL IN DEGREES, SEPARATED',/,
249               4' BY A ZERO,  HIT CARRIAGE RETURN FOR END OF DATA,',/,
250               5' OR IF THERE ARE NO MORE STRIPS,',/,' ',8)
251          101   FORMAT(3F)
252          102   FORMAT(' ONLY 20 GROUND SEGMENTS ALLOWED,  COMPUTATION WILL ',/,
253               1' PROCEED WITH DATA ALREADY OBTAINED.',/)
254          103   FORMAT(' ',8)
255          1003  FORMAT(' INPUT FLIGHT PATH TITLE',/)
256          1008  FORMAT(' INPUT FLIGHT PATH TYPE:',8)
257          1009  FORMAT(A1)
258          1010  FORMAT(' INPUT XO,XF,HI',8)
259          1011  FORMAT(' INPUT YO,LAMBDA:',8)
260          1004  FORMAT(' INPUT XO,YO,ZO:',8)
261          1005  FORMAT(' INPUT XF,YF,ZF:',8)
262          1006  FORMAT(' INPUT # OF POINTS, VELOCITY, TIME CONSTANT:',8)
263          1007  FORMAT(1,2F)
264          107   FORMAT(' INPUT ANTENNA FILE NAME:',8)
265          2000  FORMAT(A9)
266          108   FORMAT(' INPUT ANTENNA DESCRIPTION',/)
267          3001  FORMAT(67)
268                END
```

CONSTANTS

0	201004020100	1	9491004020100	2	4351004020100	3	5010004020100	4	4050064020100
5	000000000024	6	000000000001	7	000000000010	10	000000000000	11	000000000004
12	201400000000								

COMMON

XX	/.COMM./+0	YY	/.COMM./+1	ZZ	/.COMM./+2	TT	/.COMM./+3	K	/GROUND/+0
X1	/GROUND/+1	Z1	/GROUND/+39	X2	/GROUND/+51	Z2	/GROUND/+76	IEL	/GROUND/+123

SUBPROGRAMS

FORSE,	,JBFF	END,	COSD	SIND	OFILE	BINRD,	RELEAS	JOVSET	JOVNO	FLOAT	SQRT	JOVREL	SIGN	EXIT
ALPHD,	ALPHI,	FLOUT,	FLIRT,	INTO,	INTI,									

SCALARS

NAME	1407	Y0	1410	RL	1411	R	1412	ZZ	2		
THETA	1413	K	0	NSIZE	1414	I	1415	X0	1416		
XF	1417	M	1420	NX	1421	V	1422	TAU	1423		
A1	1424	A2	1425	DX	1426	XX	0	YY	1		
TT	3	IOL	1427	ZOL	1430	TEMP	1431	TEMP2	1432		
YF	1433	ZF	1434	FM	1435	DY	1436	DZ	1437		
DT	1440	N	1441	ILOL	1442	SN	1443	F	1444		
XP	1445	NEL	1446	IEL	123						

ARRAYS

IDUM	1447	ILABL	1451	X	1461	Y	1505	Z	1531
C1	1559	C2	1628	C3	1675	X1	1	Z1	25
X2	91	Z3	76						

A1	136	142	145										
A2	137	143	145										
C1	7	218	249	251									
C2	7	218	249	251									
C3	7	218	249	251									
COSD	53	54	70	71									
DT	181	191											
DX	138	152	178	181	188								
DY	179	181	189										
DZ	180	181	190										
EXIT	286												
F	227	229	231	233	236								
FLOAT	138												
FN	177	178	179	180									
GROUND	8												
H	123	136	137										
I	111	112	144	186	249	251							
IDUM	1	2	37	80	90	94	98						
IEL	8												
ILABL	4	41	81	104	105	206	248	250					
ILBL	203	247											
JOVREL	194												
JOVSET	98												
JOVND	105	132	149	176	187								
K	8	55	65	67	68	69	70	71	72	82			
N	198	207	218	219	224	225	229	231	238	240	248		
NAME	18	19	20	21	22	23							
NEL	246	249	251										
NN	130	131	138	144	174	175	177	186					
NOISE	98												
OFILE	80	94	247										
R	52	53	54	62	63	70	71						
RELEAS	83	95	252										
RL	30	136	137	231	233	236	249						
SIGN	224												
SIND	53	54	70	71									
SORT	143	145	148	191	227	229	231						
SN	224	230	232	233	236								
TAU	130	132	174	176									
TEMP	146	148											
TEMP2	147	148											
THETA	52	53	54	62	70	71							
TT	3	141	148	182	191								
V	130	148	174	181									
X	5	218	249	251									
X0	123	136	139	229	230	234	238						
X1	8	68	82										
X2	8	53	68	70	82								
XF	123	138	172	178									
XOL	142	146	150										
XP	231	232	234										
XX	3	139	142	143	145	146	149	150	152	170	178	187	188
Y	5	226	238	249	251								

YO	30	138	226	227	229	231	238							
YF	172	179												
YY	3	140	170	179	189									
Z	5	218	219	224	227	229	231	249	251					
Z1	8	69	82											
Z2	8	54	69	71	82									
ZF	172	180												
ZOL	143	147	151											
ZZ	3	52	53	54	62	64	70	71	148	147	151	170	180	190

1P	186	191							
2P	17	25	31	52	62	65	94	195	253
3P	19	256							
4P	66	74	80						
5P	63	64	67						
6P	72	75							
9P	219	246							
10P	218	241							
11P	62	76							
12P	112	157							
13P	144	153							
14P	154	194							
15P	225	229	237						
16P	228	239							
17P	230	236							
18P	237	238							
19P	231	235							
20P	20	29							
21P	21	34							
22P	22	87	131	175					
23P	23	190							
100P	42	266							
101P	30	52	62	123	170	172	271		
102P	96	95	276						
103P	73	272							
104P	38	264							
105P	37	41	81	90	104	206	238	269	
107P	199	284							
108P	203	285							
1003P	99	275							
1004P	156	280							
1005P	171	281							
1006P	124	173	282						
1007P	130	174	283						
1008P	106	276							
1009P	18	111	277						
1010P	115	278							
1011P	29	279							
1012P	24	258							
1013P	17	259							
1014P	34	260							
1015P	87	261							
1016P	250	263							
1017P	217	262							
2000P	202	265							
2001P	218	251	28[illegible]						

APPENDIX C

GLDPLT LISTING

```
SLOPLT.F4       F4D     V2B(14) 17-JUL-74       19:55   PAGE 1

                DIMENSION ITYPE(3,2)
                DATA ITYPE/'STATI','C VAL','UES','DYNAM','IC VA','LUES'/
                DATA PID,PRD/'CDID','THEOF'/
                DIMENSION SPACE(4),IAA(2,3)
                DATA SPACE/' ',2,,2,5,5,'
                DATA IAA/'DEGRE','ES',' FEET',       ,'SECON','DS'/
                DATA PRX,PRY,PRZ,PRT,PAI,PAR/
               1'RX','RY','RZ','RT','CDI','THEO'/
                DIMENSION IPTDAT(33)
                COMMON /PIX/NRP,RXMN,RXMX,RXFT,RXLT,RYMN,RYMX,RYFT,RYLT,
               2RZMN,RZMX,RZFT,RZLT,RTMN,RTMX,RTFT,RTLT,
               3AIMN,AIMX,AIFT,AILT,ARMN,ARMX,ARFT,ARLT,
               4A IL,ADIX,ADIL,ADD ,A PA,ADPF,ADPL
                EQUIVALENCE (IPTDAT(1),NRP)
                DIMENSION ILABL(8)
                DATA XLEN,YLEN,ITIC/2.,.8,.21/
                DIMENSION D1(2000),SHUF(343)
                DIMENSION D4(2000),DY(2)04)
                CALL PLOTS(IBUF,360,1H)
              3 WRITE(6,1000)
           1000 FORMAT(' INPUT FILE NAME AND AXIS TYPES:',6)
                READ(5,1005) NAME,ISX,ISY
           1005 FORMAT(A5,I,I)
                IF(ISX .LT. 1) GO TO 204
                IF(ISX .GT. 2) GO TO 204
                IF(ISY .LT. 1) GO TO 204
                IF(ISY .GT. 3) GO TO 204
                CALL PLOT(0.,+12.,+3)
                CALL PLOT(0.,1.,+3)
                I=0
                CALL IFILE(20,NAME)
                READ(20) IPTDAT
                WRITE(3,1002) NRP
           1002 FORMAT(' THERE ARE',I5,' RECEIVER POINTS,'./)
                WRITE(3,1003)
           1003 FORMAT(14X,'MIN',9X,'MAX',9X,'FIRST',8X,'LAST',/)
           1004 FORMAT(1X,A5,1X,4F12.4)
                WRITE(3,1004) PRX,RXMN,RXMX,RXFT,RXLT
                WRITE(3,1004) PRY,RYMN,RYMX,RYFT,RYLT
                WRITE(3,1004) PRZ,RZMN,RZMX,RZFT,RZLT
                WRITE(3,1004) PRT,RTMN,RTMX,RTFT,RTLT
                WRITE(3,1004) PAI,AIMN,AIMX,AIFT,AILT
                WRITE(3,1004) PAR,ARMN,ARMX,ARFT,ARLT
                WRITE(3,1004) PID,ASIN,ADIX,ACIF,ADIL
                WRITE(3,1004) PRD,ADPN,ADMX,ADPF,ADPL
                DO 7 II=1,3
                READ(20,100) ILAPL
                WRITE(3,101) ILABL
           101  FORMAT(1X,8A5)
           100  FORMAT(8A5)
                CALL SYMBOL(0.,0.,.2,ILABL,90.,.40)
              7 CALL PLOT(.3,0.,-3)
                CALL SYMBOL(0.,0.,.2,ITYPE(1,ISY),90.,10)
```

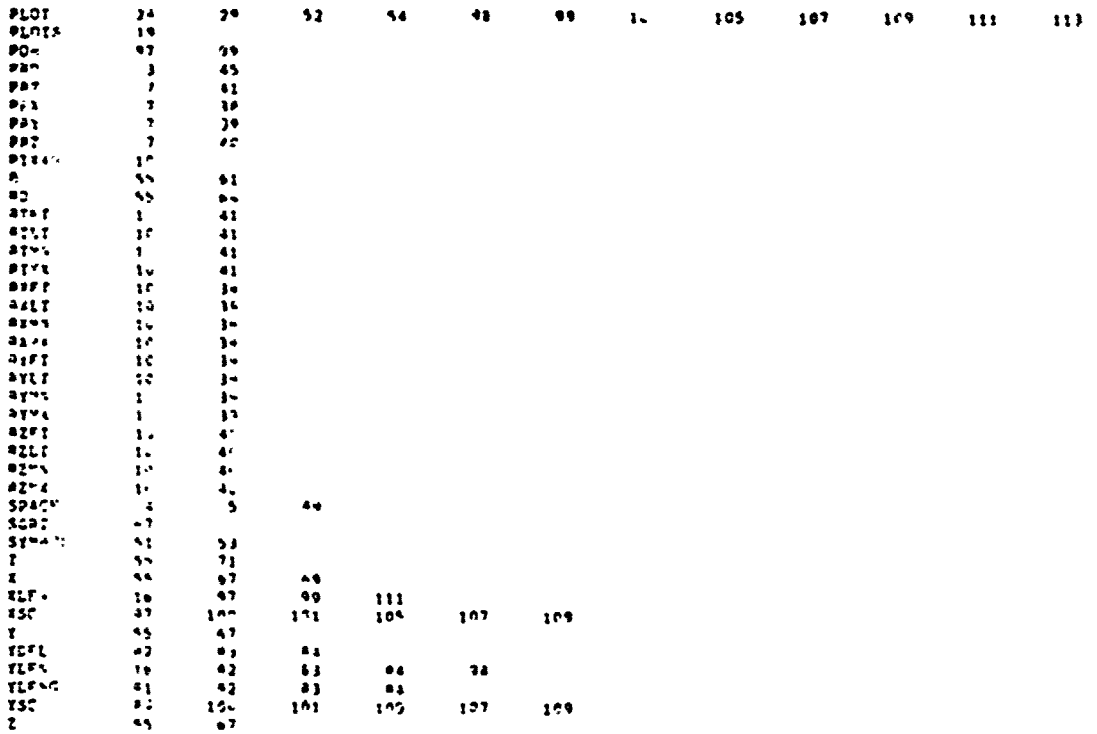
```
      54                CALL PLOT(7.,0.,-3)
      55          1     READ(20,1000,END=2) X,Y,Z,T,C,P,CD,HD
      56          1000  FORMAT(8F)
      57                I=I+1
      58                GO TO (300,301) ISY
      59          300   CONTINUE
      60                DY(I)=C
      61                DYI(I)=P
      62                GO TO 302
      63          301   DY(I)=CD
      64                DYI(I)=HD
      65          302   CONTINUE
      66                GO TO (200,201,202) INX
      67          200   DX(I)=ATAN2(Z,SQRT(X*X+Y*Y))*57.2958
      68                G  TO 1--
      69          201   DX(I)=X
      70                G  TO 199
      71          202   DX(I)=T
      72                G  TO 199
      73          199   IF(I .NE. 1) GO TO 198
      74                D
      75                D
      76          198   D
      77                D
      78          1001  F
      79                IF( I .LT. 2000) GO TO 1
      80          2     IF(I .LT. 2) GO TO 3
      81                
      82                
      83                
      84                CALL AXIS(0.,0.,
      85               1 
      86                IF=IFIX(ALOG10(D
      87                D
      88                D
      89                
      90                
      91                IF(IT .LT. ITIC) GO T
      92          120   C
      93          121   
      94                D
      95                IP=IP+1
      96                IF(IP .LT. 3) IP=
      97                CALL AXIS(0.,0.,D
      98                CALL PLOT(0.,YLEN/2.,-3)
      99                CALL PLOT(XLE
     100                
     101                CALL PLOT(DX(1)-DMIN)/XSC,DY(1)/YSC,3
     102                
     103                
     104                
     105          4     CALL PLOT((DX(J)-DMIN)/XSC,DY(J)/YSC,2)
     106                IA=2
```

```
GLOPLT.14       F4O     \2A(14) 17-JUL-74       15:59   PAGE 3


  107                   CALL PLOT((DX(1)-DMIN1)/XSC,DY1(1)/YSC,3)
  108                   DO 4 J=2,I
  109                   CALL PLOT((.X(J)-DMIN1)/XSC,DY1(J)/YSC,ISW)
  110             4     ISW=ISW-ISW
  111                   CALL PLOT(XIEW+2,,-3,,-3)
  112                   GO TO 3
  113             204   CALL PLOT(3.,3.,.999)
  114                   CALL EXIT
  115                   STOP
  116                   END

      CONSTANTS

      0       0000000000000   1       0000000000020   2       2040000000000   3       0000000000400   4       2015000000000
      5       0000000000024   6       1746314631146   7       2075500000000   10      0000000000050   11      1774631460314
      12      0000000000017   13      2024000001000   14      2067127714300   15      2044000000000   16      4662303512336
      17      4063132432644   20      4264640020100   21      0000030000000   22      0000000000014   23      1750314631466
      24      0000010000007   25      0000000000002   26      0000000000003   27      2035000000000   30      2026000000000
      31      0000000001747

      COMMON

      XEF     /PTXX/ /+0      PXMN    /PTXX/ /+1      PXMX    /PTXX/ /+2      PXFT    /PTXX/ /+3      PXLT    /PTXXN /+4
      PYMN    /PTXX/ /+5      PYMX    /PTXX/ /+6      PYFT    /PTXXN /+7      PYLT    /PTXXN /+10     PZMN    /PTXXN /+11
      PZMX    /PTXX/ /+12     PZFT    /PTXXN /+13     PZLT    /PTXXN /+14     PTMN    /PTXXN /+15     PTMX    /PTXXN /+16
      PTFT    /PTXX/ /+17     PTLT    /PTXXN /+20     AIMN    /PTXXN /+21     AIMX    /PTXXN /+22     AIFT    /PTXXN /+23
      AILT    /PTXX/ /+24     ARMN    /PTXXN /+25     ARMX    /PTXXN /+26     ARFT    /PTXXN /+27     ARLT    /PTXXN /+30
      ADIF    /PTXX/ /+31     ADIX    /PTXXN /+32     ADIF    /PTXXN /+33     ADIL    /PTXXN /+34     ADRN    /PTXXN /+35
      ADMX    /PTXX/ /+3A     ADRF    /PTXXN /+37     ADRL    /PTXXN /+40     IPTDAT  /PTXXN /+0

      SUBPROGRAMS

      FLOAT,  ,JREF   PLOTS   ALPHD,  ALPHI,  INTO,   I**I,   PLOT   IFILE   PINAR,  FLOUT,  FLINT,  SYMBOL  END,    ATAN2
      SQRT    ABIAS   AMAX1   FLOAT   IFIX    AXIS3   ALOG10  EXP1,2  EXIT

      SCALARS

      PID     1005            PSD     1006            PSX     1067            PRY     1070            PRZ     1071
      PRT     1072            PAI     1073            PAP     1074            XLEN    1075            YLEN    1076
      ITIC    1077            NUMF    1100            ISX     1101            ISY     1102            I       1103
      JUP     0               PXMN    1               PXMX    2               PXFT    3               PXLT    4
      PYMN    5               PYMX    6               PYFT    7               PYLT    10              PZMN    11
      PZMX    12              PZFT    13              PZLT    14              PTMN    15              PTMX    16
      PTFT    17              PTLT    20              AIMN    21              AIMX    22              AIFT    23
      AILT    24              ARMN    25              ARMX    26              ARFT    27              ARLT    30
      ADIN    31              ADIX    32              ADIF    33              ADIL    34              ADRN    35
      ADMX    36              ADRF    37              ADRL    40              II      1104            X       1105
      Y       1106            Z       1107            T       1110            C       1111            R       1112
      CD      1113            RC      1114            DMIN    1115            DMAX    1116            YLENG   1117
      YDEL    1120            YSC     1121            IP      1122            PON     1123            J       1124
      DEL     1125            IT      1126            XSC     1127            ISW     1130

      ARRAYS
```

	ITYPE	1131		SIACF	1137		IAY	1143	IPTDAT	0	ILABL 1151
	DYI	1161		IEOF	5101		DI	5651	DY	11571	

ADIF	1[illegible]	44												
ADIL	12	44												
ADIN	1[illegible]	44												
ADIX	1[illegible]	44												
ADMF	1[illegible]	45												
ADML	1[illegible]	45												
ADMN	1[illegible]	45												
ADMX	1[illegible]	45												
AIFT	10	42												
AILT	10	42												
AIMN	10	42	81											
AIMX	10	42	81											
ALOG10	46													
AMAX1	77	81												
AMIN1	76													
APFT	10	43												
APLT	10	43												
APMN	10	43	81											
APMX	10	43	81											
ATAN2	47													
AXIS3	84	97												
C	55	61												
CD	55	63												
DEL	89	92	93	94	97									
DMAX	75	77	86	90	94	97								
DMIN	74	76	86	90	93	97	101	105	107	109				
DX	16	67	69	71	74	75	76	77	101	102	104	105	107	109
DY	16	62	63	101	102	104	105							
DY1	17	61	64	102	104	107	109							
EXIT	114													
FLOAT	92	93	94											
I	30	57	60	61	63	64	67	69	71	73	74	75	76	77
	79	80	103	104										
IAX	4	6	97											
IBUF	17	19												
IFILE	11													
IFIX	82	86	93	93	94									
II	46													
ILAMB	15	47	48	51										
IP	86	87	95	96	97									
IP.DAT	9	18	32											
ISN	106	109	110											
ISX	22	26	27	66	97									
ISY	22	24	25	53	58									
IT	90	91												
ITIC	16	91												
ITYPE	1	2	53											
J	86	89	103	104	105	108	109							
NAME	22	31												
NBP	10	14	33											
PAI	7	42												
PAN	[illegible]	43												
PID	3	44												

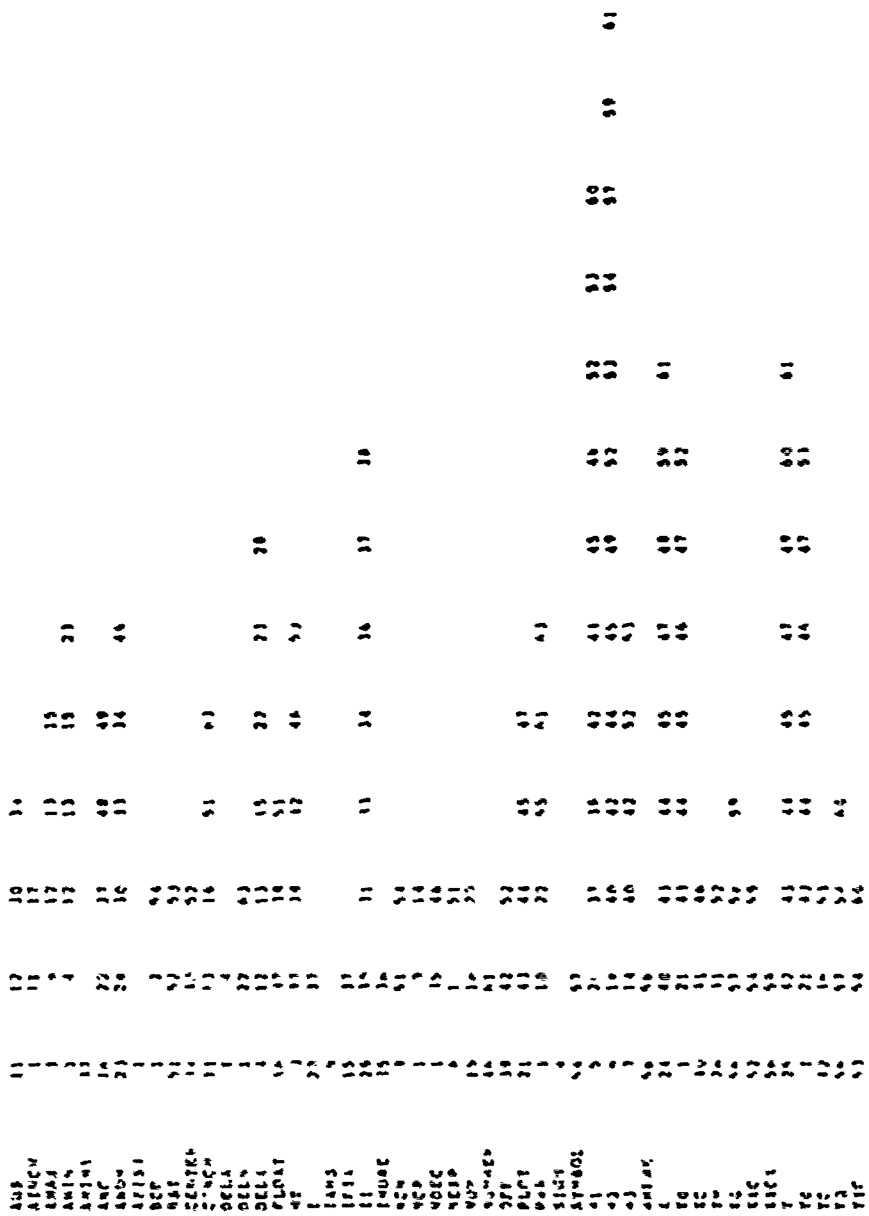
ADIF	[illegible]	44												
ADIL	[illegible]	44												
ADIN	[illegible]	44												
ADIX	[illegible]	44												
ADMF	[illegible]	45												
ADML	[illegible]	45												
ADMN	[illegible]	45												
ADMX	[illegible]	45												
AIFT	10	42												
AILT	[illegible]	42												
AIMN	[illegible]	42	81											
AIMX	[illegible]	42	81											
ALOG10	46													
AMAX1	77	81												
AMIN1	76													
APFT	10	43												
APLT	10	43												
APMN	10	43	81											
APMX	10	43	81											
ATAN2	67													
AXIS3	84	97												
C	55	[illegible]												
CO	55	63												
DEL	45	90	91	94	97									
DMAX	75	77	86	90	94	97								
DMIN	74	76	86	90	93	97	101	105	107	109				
DX	18	67	69	71	74	75	76	77	101	102	104	105	107	109
DY	16	60	63	101	102	104	105							
DY1	17	61	64	102	104	107	109							
EXIT	114													
FLOAT	42	93	94											
I	16	57	60	61	63	64	67	69	71	73	74	75	76	77
	76	80	103	104										
IAX	4	6	97											
IBUF	17	19												
IFILE	11													
IFIX	82	86	92	93	94									
II	46													
ILABL	15	47	48	51										
IP	86	87	95	96	97									
IPTDAT	9	14	32											
ISN	106	109	110											
ISX	22	26	27	66	97									
ISY	22	24	25	53	58									
IT	90	91												
ITIC	16	91												
ITYPE	1	2	53											
J	86	89	103	104	105	108	109							
NAME	22	31												
NRP	10	14	33											
PAI	7	42												
PAR	7	43												
PID	3	44												



1P	55	79								
2P	55	80								
3P	2[illegible]	80	112							
4P	1[illegible]	105								
6P	124	110								
7P	36	52								
1309P	47	51								
1317P	44	69								
1325P	86	87								
1331P	91	93								
1345P	73	78								
1403P	46	[illegible]	72	73						
2305P	--	67								
2313P	--	66								
2321P	--	71								
2334P	24	25	26	27	113					
3309P	[illegible]	[illegible]								
3319P	48	43								
3328P	42	45								
10031P	55	56								
10041P	98	100	102	104						
10052P	13	14								
10061P	35	36								
10146P	37	38	39	40	41	42	43	44	45	
10152P	22	23								
10161P	20	21								

```
CLCPLT.F4       F4D     426(14) 17-JUL-74       10:00   PAGE 5

      1               SUBROUTINE AXIS(X0,Y0,AMAX,AMIN,DELA,AINCM,BCD,NCB,ROFC,PUN,DELM)
      2               DIMENSION BCD(1)
      3               HT = .10
      4               DELA=SIGN(DELA,(AMAX-AMIN))
      5               A=90.
      6               A=90.
      7               A) = 0.
      8               XEP = 0
      9               NCH=IABS(NCB)
     10               IF(P=0.,NE.P.) XEXP = 0
     11               CINCH=ABS(AINCM)
     12               IF(ABS(AMAX-AMIN)-ABS(DELA).LT.1.E-3) GO TO 50
     13               IF((AMAX-AMIN)/(DELA+1.E-5).GT.0.OR.CINCH) DELA = (AMAX-AMIN)/CINCH
     14               IF(-DP.LT.P) XP = 1.
     15               XL=IFIX((AMAX-AMIN)/DELA+1.0)
     16               AINCH=XL*DELA/FLOAT(NUM-1)
     17               I=(AI.GE.LT.0.)GO TO 5
     18               A=1.
     19               GO TO 10
     20             5 I=1.
     21            10 CALL PLOT(X.,Y0,3)
     22               DELX=DELA/10.0*DMP/ALC
     23               AI = AMIN-DELX
     24               A=0.
     25               Y=Y.
     26               A =0.
     27               DO 40 I=1,XL
     28               AI=AMAX-DELX
     29               II=0
     30            25 IF(ABS(AI-A)/(1.0E-11.LT.1.)GO TO 30
     31               II=II+1
     32               GO TO 25
     33            30 IF(AMIN.LT.0.)II=II+1
     34               IF(ABS(AMIN).LT.1.) II=II+1
     35               I=NCH+NDEC+1
     36               II=II+IABS
     37               IF(IFIX(-1)+1.EQ.1) M1 = AMIN((MT .AND.C/FLOAT(II+2))
     38               CHSIZE = FLOAT(II)*HT/(1.0+1)
     39               OFF = .0
     40               XC = X + CHSIZE + H2O(A)*(.3G+OFF*IFB) - .15)
     41               IF(XC.LT.A)XC=XC
     42               YC = Y - .1*(A + .1A - H)*(HT+.3)) - H2*OFF
     43               CALL PLOT(XC+A,YC+Y,2)
     44               CALL PLOT(XC+A-.10+2.YC+Y+.10+1,3)
     45               CALL PLOT(XC+A-.10+2,YC+Y-.10+1,2)
     46               CALL NUMBER(XC+AC,YC+YC,HT.ANUM,0.,NDEC)
     47               CALL PLOT(XC+A,YC+Y,3)
     48               XAX=AXC+1
     49               YAY=AYC+2
     50            40 CONTINUE
     51               PST = (CINCH - FLOAT(NCH+A(EXP)+.12)/2.
     52               XXC = A1*(XC + PST) + H2*(XC + A - OFF + A)*(3.*CENTER+.44))
     53               YYC = A1*(YC + YC - .17 + A)*(HT + .22) ) + H2*(YC + PST)
```

```
GLOPLT.FT       V4C     #20(114) 17-JUL-78      18:03   PAGE 6

                CALL SYMBOL(XXC,YYC,.12,PCD,90.,0.2,ACH)
                IF(I.GT.1) PEN(3,
                CALL NUMBER (XX,YG,YYC)
                CALL SYMBOL(XX,YG,.12,5H * 10,90,0.2,5)
                CALL NUMBER (XX,YG,EXC)
                X = X. + (XXC-.08-2G)*0.2
                Y = Y. + (YYC-.08-YG)*0.1
                CALL SYMBOL(X,Y,.08,E-P,90,0.2,-1)
                RETURN
             50 PRINT 6 I,E-3010,0.0E-0/CINCH
                WRITE(6,1000)
           1000 FORMAT(1H0,27HINSUFFICIENT RANGE FOR AXIS )
                METHOD
                END

 CONSTANTS

 .          1756311631464     1          16746011115444    2          1605174265642     3          2017463146431     4          000000000003
 5          2014000000000     6          1756311463146     7          1756311463214     10         1756631166314     11         0000000000002
 12         0000050000000     13         1753534123772     14         1777024188800     15         1758341211727     16         1767026366860
 17         3012446310560     20         0000000000000     21         0000000000005     22         1755075346121     23         1755605807834

 GLOBAL DEFINES

 XO      634             YC      635             AMAX    636             AMIN    637             DELA    640
 AINCH   641             PCD     642             NCH     643             NDEC    644             PWR     645
 DELY    646

 SUBPROGRAMS

 SIGN    IABS    ABS     IFIX    FLOAT   PLOT    EXP3,2  EXP2,2  AMIN1   NUMBER  SYMBOL  WHERE

 SCALARS

 AXIS1   651             MT      652             DELX    653             DELA    640             AMAX    636
 AMIN    637             MJ      654             MJ      655             MJ      656             NZEP    657
 XCH     660             NCH     643             PWR     645             CINCH   661             AINCH   641
 NUM     662             ANC     663             XO      634             YO      635             DELH    646
 EXCH    664             Y       665             Y       666             XN      667             I       670
 II      671             IAOPE   672             NDEC    644             CENTER  673             OFF     674
 YC      675             YC      676             BAT     677             XXC     700             YYC     701
 YG      702             YG      703             XACX    704

 ARRAYS

 ACH     643
```



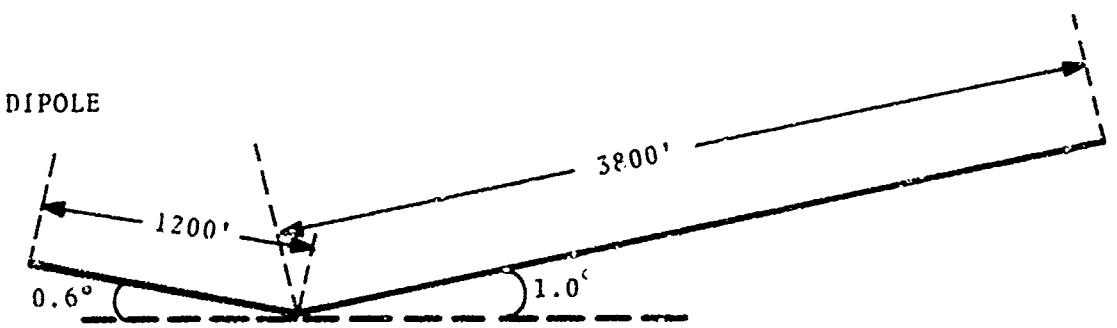
5P	17	2[illegible]
10P	[illegible]9	2[illegible]
20P	3[illegible]	33
35P	30	32
40P	27	50
50P	17	43
100P	66	65

APPENDIX D

EXAMPLE

In this Appendix a test case is presented which the programmer may duplicate to gain experience in running the model.

The test case uses a Null Reference antenna over a terrain as sketched below.



The results are shown in Figure 9.

Figure 9.. Test Case Results

```
16:50:30 $VERS  BATCON 10(107) INFO SUBJOB 01 OF 01
16:50:50 $DATE  17-Aug-74
16:50:50 $ASUN  [TEST][161,365] FOR ANENSONO[3,43,1652] SYS FILE SY:  [161,365]
                Request created at  16:50:04 17-Aug-74
                Unique: 2 Position: 0
16:50:54 MONTR
.0:50:50 MONTR  .LOGIN 161,365
16:50:54 USER   JOB 16 TTY DECSYSTEM-1X50 10003 TTY97
16:50:54 USER   Other jobs same PPN
16:50:54 USER   1650    13-Aug-74       Tue
16:50:54 MONTR
16:50:54 MONTR  .GET TIME SAVE
16:50:5C MONTR
16:50:54 MONTR  .SET SPOOL ALL
16:50:54 MONTR
16:50:54 MONTR  ..RUN FRAKE
16:50:54 USER
16:50:55 USER
16:50:55 USER   INPUT SWITCH.Y
16:50:55 USER
16:50:55 USER   INPUT Y1.LAMBDA[300,,3,
16:50:59 USER
16:50:59 USER   INPUT SWITCH.G
16:50:59 USER
16:50:59 USER   INPUT GROUND FILE NAME:GRND
16:50:59 USER
16:50:59 USER   INPUT GROUND LABEL
16:50:59 USER   THIS IS A DEMONSTRATION CASE
16:50:59 USER
16:50:59 USER   INPUT GROUND INCREMENTS.  STARTING FROM ANTENNA,
16:50:59 USER   GIVE CONSECUTIVELY EITHER 1 AND 2 INCREMENTS, OR THE
16:50:59 USER   LENGTH AND ANGLE FROM HORIZONTAL IN DEGREES, SEPARATED
16:50:59 USER   BY A ZERO.  HIT CARRIAGE RETURN FOR END OF DATA,
16:50:56 USER   OR IF THERE ARE NO MORE STD.PS.
16:50:56 USER   <0,,0.
16:50:59 USER
16:50:59 USER   <1200,,0,,-,4
16:51:00 USER
16:51:00 USER   <1800,,0,,1,
16:51:01 USER
16:51:01 USER   4
16:51:05 USER
16:51:05 USER   INPUT SWITCH.F
16:51:05 USER
16:51:05 USER   INPUT FLIGHT PATH FILE NAME:FLIDE
16:51:07 USER
16:51:07 USER   INPUT FLIGHT PATH TITLE
16:51:07 USER    HYPERBOLIC FLIGHT PATH 1500A
16:51:10 USER
16:51:10 USER   INPUT FLIGHT PATH TYPE:G
16:51:11 USER
16:51:11 USER   INPUT X0,XF,N:20000,,1000,,30,
16:51:11 USER
16:51:11 USER   INPUT 3 OF POINTS, VELOCITY, TIME CONSTANT:200,300,,,4
16:53:33 USER
16:53:33 USER   INPUT SWITCH.A
16:53:33 USER
16:53:33 USER   INPUT ANTENNA FILE NAME:BOLT1
16:53:34 USER
16:53:34 USER   INPUT ANTENNA DESCRIPTION
```

```
16:53:34 USER   NULL REFERENCE ANTENNA
16:53:34 USER
16:53:34 USER   INPUT ELEMENT VALUES..
16:53:34 USER   0.,15.,.1..0.,.,4.0:.,4.0.
16:53:34 USER   0.,30.,.0..0.,.,.12.0,...12.0.
16:53:35 USER   0.,0.,0.
16:53:35 USER
16:53:35 USER   INPUT SWITCH:
16:53:36 USER
16:53:36 USER
16:53:36 USER   CPU TIME: 0.03  ELAPSED TIME: 2:00.33
16:53:36 USER   NO EXECUTION ERRORS DETECTED
16:53:37 MONTR
16:53:37 MONTR  EXIT
16:53:37 MONTR
16:53:37 MONTR  .
16:53:37 MONTR  ..R PIP
16:53:37 USER
16:53:37 USER   *PATH.DAT,CLOSE.DAT
16:53:37 USER   *^C
16:53:37 MONTR  .
16:53:37 MONTR  ..RUN ILSCLO
16:53:37 USER
16:53:38 USER
16:53:38 USER    839 RECORDS IN PATH.DAT
16:53:38 USER
16:53:39 USER   INPUT ANTENNA FILE NAME:NULL1.
17:25:28 USER
17:25:28 USER
17:25:28 USER   CPU TIME: 11:44.57     ELAPSED TIME: 31:49.55
17:25:28 USER   NO EXECUTION ERRORS DETECTED
17:25:28 MONTR
17:25:28 MONTR  EXIT
17:25:28 MONTR
17:25:28 MONTR  .
17:25:28 MONTR  .
                A1
17:25:28 MONTR   .MOUNT MTA:16/VID:'SCRATCH PLOT TAPE'/WRABL
17:25:29 USER   OPERATOR NOTIFIED
17:25:30 USER   WAITING...
17:27:19 USER   16 (MTA1)  MOUNTED
17:27:19 USER
17:27:20 MONTR  .
17:27:20 BATCH  .IF(ERROR) .GOTO 8
17:27:20 MONTR  .ASSIGN BLOCKSIZE 16384
17:27:20 MONTR  .
17:27:20 BATCH  .IF(NCERECB)
                .GOTO C
                8$: .SUBMIT TEST/TIME=1000/AFTER:+0:05/TAG:A
                .E/F/I:0
                C$
                 :CONTINUE
17:27:20 MONTR  .RUN GLOPLT
17:27:20 USER
17:27:21 USER
17:27:21 USER   INPUT FILE NAME AND AXIS TYPES:STRIP 2 1
17:27:27 USER
17:27:27 USER          1300.+000000    -64.0000000
17:27:27 USER   INPUT FILE NAME AND AXIS TYPES:STRIP 2 2
17:27:35 USER
17:27:35 USER          1300.0000000    -64.0000000
```

```
17:27:38 USER   INPUT FILE NAME AND AXIS TYPES:
17:27:38 USER
17:27:38 USER
17:27:38 USER   CPU TIME: 13.05 ELAPSED TIME: 14.93
17:27:39 USER   %J EXECUTION ERRORS DETECTED
17:27:39 *CNTR
17:27:39 *CNTR  EXIT
17:27:39 *CNTR
17:27:39 *CNTR  .
17:27:39 *CNTR  ..PLEASE PLOT TAPE ******************************$(
17:27:39 *CNTR
17:27:39 *CNTR  ..DISMOUNT 101
17:27:39 USER   OPERATOR NOTIFIED
17:27:40 USER   %AITING...
17:27:42 USER   10 DISMOUNTED
17:27:42 *CNTR
17:27:42 *CNTR  ..PRINT/DISPOSE:SPOOL STRIP.DAT
17:27:43 USER   Total of 42 blocks in 1 file in LPT request
17:27:43 *CNTR
17:27:43 *CNTR  ..PRINT *.LPT
17:27:46 USER   Total of 39 blocks in 1 file in LPT request
17:27:46 *CNTR
17:27:46 *CNTR  ..PRINT *.LPT,TEST,LOG/AFTER:+1:::
17:27:47 USER   %-LOGSF %g user files as DSKB:,LPT:[161,345]
17:27:47 USER   Total of 7 blocks in 1 file in LPT request
17:27:47 *CNTR
17:27:47 *CNTR  ..@ JOBCOM
17:27:48 USER
17:27:48 USER   LOGIN TIME (EXAMPLE: 16:05): 0:30
17:27:48 USER   CONNECT COST = $    130.00
17:27:48 USER   CPU COST = $     91.09
17:27:48 USER   DISK ACCESS COST = $     01.93
17:27:48 USER   ESTIMATED OTHER COSTS = $     45.99
17:27:48 USER   ESTIMATED TOTAL COST = $    229.00
17:27:48 *CNTR  EXIT
17:27:48 *CNTR
17:27:48 *CNTR  ...^/F
17:27:50 USER   .   14, User [3161,345]  Logged off TTY67    1727  13-Aug-74
17:27:50 *CNTR  Saved all files (660 blocks)
17:27:51 *CNTR  Runtime 13 min. 10.41 Sec
```